YEAR 2003
WATER QUALITY DATA REPORT

Green-Duwamish Watershed
Water Quality Assessment

March 2005

Prepared for

King County
Department of Natural Resources and Parks

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WATER QUALITY DATA REPORT

Green-Duwamish Watershed Water Quality Assessment

Prepared for

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1.0 Introduction

King County (and previously the Municipality of Metropolitan Seattle) has conducted water quality sampling in the Green-Duwamish watershed since 1970. In the past, the goal of this monitoring has been to provide information about local surface waters in the Seattle/King County metropolitan area in support of programs designed to protect water quality and abate water pollution. Fourteen sites in the Green-Duwamish Watershed have been monitored since the mid-1970s.

In 2001, King County initiated a separate comprehensive study of the Green-Duwamish watershed, called the Green-Duwamish Watershed Water Quality Assessment (GDWQA) Comprehensive Monitoring Program. The primary purpose of this program is to collect and analyze water quality data within the Green-Duwamish watershed and to use these data to support the following efforts and teams (King County 2002):

- Wastewater Treatment Division Habitat Conservation Plan (WTD HCP) team
- The WTD combined sewer overflow (CSO) control planning team
- The Water Resources Inventory Area (WRIA) 9 Planning Work Group, Technical Committee and Steering Committee
- Washington State Department of Ecology (Ecology) Total Maximum Daily Load (TMDL) efforts.

The primary goal of this monitoring program is to develop analytical tools for evaluating current and future water quality and quantity issues in the Green-Duwamish watershed, and to provide water quality information to clients both internal and external to King County's Department of Natural Resources and Parks (DNRP). For example, data from the GDWQA will be used for wastewater capital planning, Water Resource Inventory Area (WRIA) 9 salmon conservation planning, stormwater management efforts, and Washington State Department of Ecology's Total Maximum Daily Load (TMDL) program. The scope of work of this program includes water quality and hydrologic monitoring, land use/land cover modeling, water quality and quantity modeling, best management practice (BMP) evaluation, and aquatic life risk assessment.

In support of this monitoring program, Herrera Environmental Consultants, Inc. (Herrera) was retained by the County to evaluate and summarize Green-Duwamish water quality data collected from 2001 through 2003. Information from the first year of monitoring (2001-2002) was summarized by Herrera (2004). This document represents the second water quality data report and evaluates data collected during the 2003 calendar year. A water quality loadings report will then be prepared that presents methods, results, and detailed analyses of the 2001-2003 data including a hydrologic data analysis, pollutant loading calculations, analysis of land use loading factors, and statistical analysis. Results from water quality monitoring conducted in the Green-Duwamish watershed prior to 2000 are presented in the Habitat Limiting Factors and

Reconnaissance Assessment Report (Kerwin and Nelson 2000) and are also summarized below in Section 2.2 of this report for select waterbodies.

1.1 Goals and Objectives

The objectives of the Green-Duwamish Watershed Water Quality Assessment Comprehensive Monitoring Program are to:

- Measure water quality parameter concentrations in different geographic areas of the watershed throughout the year, including at the mouths of major tributaries and at sub-watershed boundaries within the mainstem Green River
- Measure water quality parameter concentrations resulting from different land use/land cover types within select tributary subbasins
- Measure water quality parameter concentrations in the mainstem, major streams, and select tributaries during both storm and baseflow conditions
- Measure water quality parameter concentrations as a function of the rise, peak, and fall of the corresponding stream hydrograph to determine the variability of parameter concentrations within a storm
- Collect sufficient data to support development and calibration of water quality models for the Green-Duwamish watershed.

Water quality monitoring for the GDWQA was conducted according to the sampling and analysis plan (King County 2002), and involves collecting water samples at 18 sites located in the lower and middle segments of the Green-Duwamish watershed. Two of these sites are located on the mainstem of the Green River and five sites are located near the mouths of four major tributary streams including Springbrook Creek (Black River), Mill Creek, Soos Creek, and Newaukum Creek. The remaining 11 sites are located on tributaries representing different land uses including forest (three sites), agriculture (two sites), low-medium development (four sites), and high development (two sites) (King County 2002). A total of 17 sites were monitored in 2003 because one of the tributaries representing forest land use was not monitored due to site access restrictions.

This report characterizes the existing conditions in the Green-Duwamish Watershed based on sampling that was conducted at GDWQA monitoring sites during the 2003 calendar year. The specific goals of this report are as follows:

- Characterize existing water quality conditions in the Green-Duwamish Watershed based on comprehensive monitoring data collected in 2003 for the GDWQA comprehensive monitoring program.

- Evaluate significant spatial patterns in the water quality data for the 17 monitoring locations.

- Identify sites with impaired water quality and those parameters of concern causing impairment.

1.2 Report Organization

This report is organized to include the following components:

- Introduction
- Watershed Overview
- Sampling and Laboratory Analysis Methods
- Data Management and Analysis Methods
- Data Evaluation and Results
- Conclusions
- References.

The Watershed Overview (Section 2.0) describes physical features and land use characteristics of the Green-Duwamish River and its tributaries. This section also includes a general discussion of historical water quality data collected within the watershed.

The Sampling and Laboratory Analysis Methods (Section 3.0) includes an overview of the 2003 sampling locations, sample types and sampling frequency, sample collection procedures, sample documentation and handling procedures, sampling parameters, laboratory analysis methods, quality control procedures, and data reporting and recordkeeping procedures. The Data Management and Analysis Methods (Section 4.0) includes a description of the procedures used for data compilation and management, computation of summary statistics, comparison of results to the applicable water quality criteria, spatial pattern analysis, and a discussion of the water quality index (WQI) ranking system.

The Data Evaluation and Results (Section 5.0) summarizes water quality data collected for the GDWQA in 2003. In order to provide some context for interpreting these data, this section begins with an evaluation of precipitation totals from the current monitoring period relative to historical precipitation totals. Results from the water quality monitoring are then presented under separate subsections for each of the following major parameter categories: in-stream measurements, conventionals, microbiological parameters, nutrients, metals, minerals, and priority pollutant organics. For each set of parameters identified, this section includes an overview discussion, summary statistics and comparison of results to the water quality criteria, and a spatial pattern analysis. The statistics include box plots exhibiting storm and base flow data for each parameter. Finally, this section presents and discusses Water Quality Index (WQI) scores for each of the monitoring sites.

The Conclusions (Section 6.0) summarizes the existing water quality conditions in the Green-Duwamish watershed. This section describes specific subbasins/streams with impaired water quality and identifies the associated parameters that are responsible for the impairment. This section also describes any significant spatial patterns that were identified through a statistical analysis of the data. The References (Section 7.0) lists all references that are cited within this document. Supporting documentation for the sections above is also provided in Appendices A through Q.

2.0 Watershed Overview

This section describes the physical features and land use characteristics of the Green-Duwamish watershed and the individual stream basins studied. Also included is a general discussion of historical water quality data collected within the watershed.

2.1 Physical Features and Land Use Characteristics

This section summarizes physical features and land use patterns in the Green-Duwamish watershed and the studied stream basins as described in the WRIA 9 Habitat-limiting Factors and Reconnaissance Assessment Report completed by King County (2000).

2.1.1 Green-Duwamish Watershed

The Green-Duwamish watershed is located in Water Resource Inventory Area 9 (WRIA 9), which is located entirely within King County, Washington (Figure 1). The watershed comprises a drainage area of approximately 484 square miles, consisting of the Puget lowland and Cascades ecoregions (Ecology 1995; King County 2002). The watershed extends from the crest of the Cascade Mountains at the headwaters of the Green River, west to the mouth of the Duwamish River where the river empties into Elliott Bay at the City of Seattle. The average areal precipitation is 59 inches per year within the watershed (Ecology 1995). The Green-Duwamish watershed is comprised of the following subwatersheds (Figure 2):

- Upper Green River subwatershed covering 219.7 square miles above river mile (RM) 64.5 at Howard Hanson Dam
- Middle Green River subwatershed covering 177.5 square miles from RM 64.5 to RM 32.0 at Auburn Narrows
- Lower Green River subwatershed covering 63.8 square miles from RM 32.0 to RM 11.0 at Tukwila
- Green-Duwamish Estuary subwatershed covering 22.2 square miles from RM 11.0 to RM 0.0 at Elliott Bay.

The GDWQA study area encompasses 264 square miles of the Green-Duwamish watershed that extends from Howard Hanson Dam (RM 64.5) to the mouth of the Duwamish River (RM 0) (King County 2002). The Upper Green River sub-watershed (220 square miles) above Howard Hanson Dam is not included in this study. Major cities that are located within the study area include Seattle, Renton, Kent, Auburn, Tukwila, and Enumclaw. Major streams draining to the Green River within the study area include Soos, Newaukum, Mill (Hill), and Springbrook creeks.

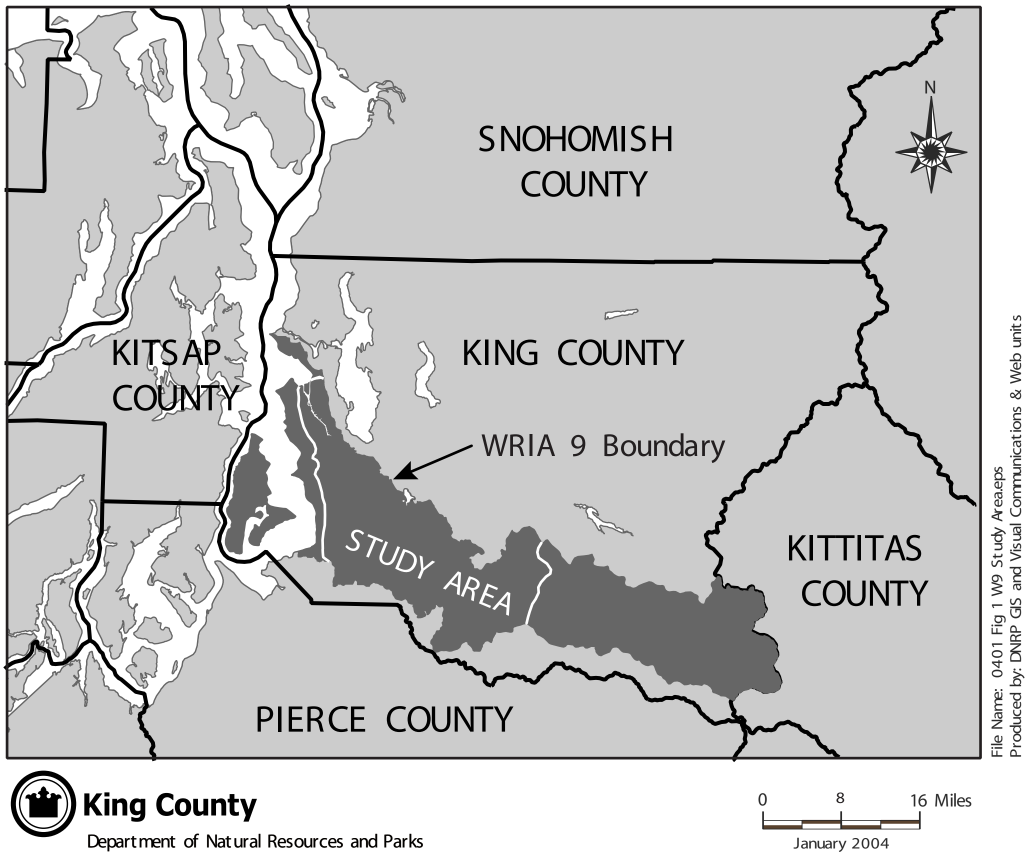

Figure 1. Location of the Green-Duwamish watershed study area in WRIA 9, Washington.

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Figure 2. Land use and cover circa 1995, WRIA 9

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Land use and cover (circa 1995) in WRIA 9 are presented in Figure 2. Designated land use in WRIA 9 is presented in Figure 3. Land use in the Upper Green River watershed (not included in the study area) is dominated by forest and forestry practices and serves as the drinking water watershed for the City of Tacoma. Land use in the Middle and Lower Green River subwatersheds is dominated by agriculture and low- to high-density residential development with some forested areas. The Green-Duwamish Estuary subwatershed is an urban industrialized area serving the City of Seattle.

2.1.2 Major Stream Basins and Tributary Subbasins

In order to address watershed variability, the monitoring study targeted major stream basins and tributary subbasins having varied land uses and a wide geographic distribution across the Green River watershed (King County 2002). Based on this criterion, the major stream basins selected were Springbrook Creek (including the Black River), Mill (Hill) Creek, Soos Creek, and Newaukum Creek; and the tributary subbasins selected were Hamm Creek, Mill Creek (in Springbrook Creek basin) tributary, Panther Creek (in Springbrook basin), an unnamed Green River tributary at Lea Hill, Soosette Creek (in Soos Creek basin), Crisp Creek, four Newaukum Creek tributaries, and an unnamed Green River tributary near RM 61. The station located at the unnamed Green River tributary near RM 61 was excluded from the monitoring program in 2003 because the land owner terminated the access agreement with King County. These major stream basins and their associated tributaries are described below.

2.1.2.1 Springbrook Creek Basin

Springbrook Creek flows via the Black River into the Lower Green River at RM 11.0 where the Green River becomes the Duwamish River. The drainage basin is approximately 24 square miles in area, and is located on the east side of the Lower Green River, within the cities of Renton and Kent. Because of prior drainage modifications (diversion of the Black River from Lake Washington), the major stream draining the basin is now Springbrook Creek (Kerwin and Nelson 2000). Springbrook Creek is approximately 12 miles in length and becomes the Black River at a point 0.65 miles upstream of the Green River (WDF 1975). Historically, the Black River drained Lake Washington, and combined with the Cedar River and then Springbrook Creek before it merged with the Green River to become the Duwamish River. Since construction of the Lake Washington Ship Canal in 1916, the Black River receives very little drainage besides that in Springbrook Creek.

Basin land use consists of low- to high-density development and includes portions of the cities of Kent and Renton. Panther Creek and Mill Creek are two of the largest streams within the Springbrook Creek basin. Panther Creek flows from Panther Lake into Springbrook Creek at RM 1.3 (WDF 1975). Mill (Springbrook) Creek is located entirely in the Green River valley and flows into Springbrook Creek at RM 3.8. Land use in the Panther Creek subbasin consists of low- to medium-density development, whereas land use in the Mill (Springbrook) subbasin consists of higher density development.

2.1.2.2 Mill (Hill) Creek Basin

Mill (Hill) Creek, which has been referred to as Hill Creek in various literature sources, differs from the Mill Creek located in the Springbrook Creek basin. Mill (Hill) Creek flows into the Lower Green River at RM 23.9 and is approximately 8.35 miles long (WDF 1975). The Mill (Hill) Creek drainage basin covers an area of approximately 22 square miles and includes portions of the Cities of Kent, Auburn, Algona, and Federal Way (Kerwin and Nelson 2000). Mill (Hill) Creek flows originate from Lake Doloff and Lake Geneva located west of the Green River Valley. Adjacent Lower Green River tributaries include Mullen Slough and Midway Creek. Prior to reaching the valley floor and flowing into the Green River, Mill (Hill) Creek flows down a steep ravine (Peasley Canyon). Land use in the Mill (Hill) Creek subbasin consists of forested areas and residential land use in the upper watershed and residential and agricultural land use in the lower parts of the basin.

2.1.2.3 Soos Creek Basin

Soos Creek flows into the Middle Green River at RM 33.7 and is 14.15 miles long (WDF 1975). The drainage basin includes over 60 miles of streams and includes 25 tributaries. The Soos Creek drainage basin is approximately 70 square miles in size and is located southeast of Renton and east of Kent (Kerwin and Nelson 2000). Soos Creek subbasin land use/cover consists of rural residential, agriculture, and highly urban commercial and residential areas, and includes a Washington State Department of Fish and Wildlife salmon hatchery near the mouth of Soos Creek. Soosette Creek is a tributary that enters Soos Creek at RM 1.35. Soosette Creek subbasin land use consists of low- to medium-density development. Jenkins Creek and Covington Creek are also tributaries of Soos Creek, but were not sampled as part of the GDWQA.

2.1.2.4 Newaukum Creek Basin

Newaukum Creek, the uppermost major stream included in this study, flows into the Middle Green River at RM 40.7 and is 14.35 miles long (WDF 1975). The basin covers an area of over 27 square miles (Kerwin and Nelson 2000). The creek flows from the mountains east of the City of Enumclaw through the Enumclaw valley and then into the Green River. Basin land use consists of high-density development, agriculture/pasture, and forest/forestry practices. Four unnamed Newaukum Creek tributaries were monitored in this study. The Newaukum Creek tributary at Enumclaw (site I322B) represents high-density development. Newaukum Creek tributaries at SE 424th Street ditch (site B322) and 236th Avenue SE (site D322) represent agriculture and pasture land use. The Newaukum Creek tributary downstream of Weyerhaeuser (site S322) represents forestry and forest practices.

2.1.2.5 Hamm Creek Basin

Hamm Creek is located immediately south of the Seattle City limits and flows into the Duwamish River at RM 4.95. The stream is less than 1 mile in length (WDF 1975). Land use in the Hamm Creek basin consists mostly of low- to medium-density development, with a forested riparian corridor in the upper basin (Kerwin and Nelson 2000).

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Figure 3. Designated land use, WRIA 9

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2.1.2.6 Lea Hill Basin

An unnamed tributary (WRIA stream 09-0069) flows into the Green River at RM 30.15. The stream is approximately 1 mile in length, and drains the Lea Hill area located east of Auburn and consists of low- to medium-density development.

2.1.2.7 Crisp Creek Basin

Crisp Creek is a small stream that flows into the Middle Green River at RM 40.1, just west of the City of Black Diamond. The drainage basin is approximately 4.5 square miles in size and the stream is 3.55 miles in length (Kerwin and Nelson 2000; WDF 1975). Land use in the Crisp Creek basin consists of forest/forest practices with rural zoning, as well as a salmon hatchery operated by the Muckleshoot Indian Tribe. A portion of the streamflow is contributed by springs (i.e., ground water).

2.1.2.8 Unnamed Green River Tributary Basin

The furthest upstream tributary monitored for this study is an unnamed tributary (WRIA 09-0157) that flows into the Green River near the City of Tacoma's diversion dam at RM 61. Land use in the unnamed tributary basin consists of forest/forestry practices. This station was dropped from monitoring in December 2002 because the land owner terminated the access agreement with King County.

2.2 Historical Water Quality Conditions

This section summarizes historical water quality conditions in the Green-Duwamish watershed as described in the WRIA 9 Habitat Limiting Factors and Reconnaissance Assessment Report prepared by King County (2000). These historical water quality data indicate that water quality conditions vary widely throughout the watershed and among the various drainage sub-basins.

2.2.1 303(d) Water Quality Limited Water Bodies

Section 303(d) (and later revisions) of the Clean Water Act (CWA) requires all states to prepare a list of surface waters that are not expected to meet applicable water quality criteria following implementation of water quality based controls. This list, identified as the 303(d) list, is prepared by Ecology and submitted to the U.S. EPA (EPA) every 2 years. The 1998 303(d) list is the most recent list prepared by Ecology and approved by EPA. A 303(d) list was not required by EPA for 2000, and the second draft of the draft 303(d) list for 2002/2004 was issued by Ecology in November 2004 for public review. Further, the CWA requires states to establish Water Clean-Up Plans or Total Maximum Daily Loads (TMDLs) for parameters identified on the 303(d) list that do not meet applicable water quality criteria.

Numerous waterbodies in the Green-Duwamish watershed are included on Ecology's 1998 303(d) list (Figure 4). Waterbodies listed include the Duwamish Waterway and River, Lower Green River, Middle Green River, Upper Green River, Springbrook Creek, Mill (Hill) Creek, Soos Creek, Newaukum Creek, and Crisp Creek. Table 1 identifies the parameters listed on the 1998 303(d) list in the Green-Duwamish watershed. As part of the TMDL process, Ecology proposes to begin water clean-up planning in 2004 for the Green and Duwamish Rivers; and Big Soos, Newaukum, Springbrook and Mill (Hill) Creeks (Ecology 2003).

Table 1. Water bodies monitored for the Green-Duwamish watershed water quality assessment identified on Washington State's 1998 303(d) list.

Water Body	Listed Parameter(s) [a]
Lower Green River (RM 11.0 to 32.0)	Temperature, fecal coliform bacteria, chromium, and mercury
Middle Green River (RM 32.0 to 64.5)	Temperature and fecal coliform bacteria
Springbrook Creek	Temperature, dissolved oxygen, fecal coliform bacteria, cadmium, chromium, copper, mercury, and zinc
Mill (Hill) Creek	Temperature, dissolved oxygen, and fecal coliform bacteria.
Soos Creek, Soosette Creek	Temperature, dissolved oxygen, and fecal coliform bacteria
Newaukum Creek	Dissolved oxygen, fecal coliform bacteria, and ammonia nitrogen
Crisp Creek	Fecal coliform bacteria

Source: Kerwin and Nelson 2000 and Ecology 1998.
[a] Table shows listings for water quality parameters not meeting applicable criteria, but does not include sediment and tissue parameters.

2.2.2 Green River

Based on recent water quality data collected between 1996 through 1999, the Lower Green River (RM 11.0 to RM 32.2) can be characterized as having fair to good water quality. This reach of the river is listed as impaired on Ecology's 1998 303(d) list for temperature, fecal coliform, chromium, and mercury. Past sampling results indicate that river waters do not always meet state criteria for water temperature and dissolved oxygen during the mid- to late-summer. The river generally has low turbidity, with peak values observed during storm events. River waters can also be slightly acidic and not meet Ecology's minimum pH criterion of 6.5. Based on samples collected in 1996 through 1999, ammonia nitrogen concentrations met state chronic and acute criteria. River waters exhibit low concentrations of metals, with the exception of aluminum, which did not meet the EPA (2002a) chronic criterion of 87 µg/L during three sampling events. (Aluminum data are compared to the EPA criteria because Washington State does not have a surface water quality criterion for aluminum [WAC 173-201A]. Because there are no state water quality criteria for aluminum, no 303(d) listing has been established.)

The Middle Green River (RM 32 to RM 63.8) generally exhibits good water quality. Past sampling results indicate that river waters have reasonably moderate summer temperatures, and are generally clear and well oxygenated with occasionally elevated fecal coliform bacteria concentrations. This reach of the river is included on Ecology's 1998 303(d) list as impaired for

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Figure 4. Water bodies and parameters on the 1998 303(d) list for water, WRIA 9

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temperature and fecal coliform bacteria. King County-measured ammonia-nitrogen concentrations met state criteria during all sampling events from 1996 through 2000. River waters generally met the state's pH criteria range of 6.5 to 8.5 and exhibited low metals concentrations, with the exception of aluminum. Additionally, one pH value was less than the minimum criterion of 6.5. Three sample results exceeded the EPA (2002) chronic aluminum criterion (87 µg/L) and one sample result exceeded the EPA acute criterion of 750 µg/L.

2.2.3 Major Streams and Tributary Sites

Past sampling indicates that water quality conditions in the major streams and tributary sites vary considerably throughout the watershed. Springbrook Creek, Mill (Hill) Creek, Soos Creek, Newaukum Creek and Crisp Creek are identified on Ecology's 1998 303(d) list as impaired waterbodies (Table 1). Historical water quality data are not available for the other tributary sites included in this study and, therefore, are not summarized in this report. Major stream and tributary water quality patterns presented below are based on sampling results summarized in the Habitat Limiting Factors and Reconnaissance Assessment Report (Kerwin and Nelson 2000) and results from monitoring conducted during 2000 (see Appendix A).

2.2.3.1 Springbrook Creek

Springbrook Creek does not always meet applicable state water quality criteria (WAC 173-201A) for dissolved oxygen, temperature, pH, fecal coliform bacteria, and numerous metals. Stream waters have been observed to be warm, poorly oxygenated, turbid, and to exhibit elevated fecal coliform bacteria concentrations. Ammonia nitrogen concentrations met applicable state criteria during all sampling events from 1996 through 2000. However, three pH measurements did not meet the state's minimum criterion of 6.5 during this period. Three samples exceeded the EPA (2002a) chronic aluminum criterion (87 µg/L) and two samples exceeded the EPA acute aluminum criterion of 750 µg/L. Springbrook Creek is included on Ecology's 1998 303(d) list as impaired for dissolved oxygen, temperature, fecal coliform bacteria, and for the metals cadmium, chromium, copper, mercury, and zinc.

2.2.3.2 Mill (Hill) Creek

Mill (Hill) Creek sampling results indicate that stream waters do not always meet applicable state water quality criteria (WAC 173-2-201A) for temperature, dissolved oxygen, pH and fecal coliform bacteria. During sampling, stream waters were poorly oxygenated, turbid, and exhibited elevated fecal coliform bacteria concentrations. Erosion along the streambanks within Peasley Canyon have caused high suspended solids and turbidity downstream (Kerwin and Nelson 2000). Elevated water temperatures have been measured downstream of Peasley Canyon to the stream's mouth (Kerwin and Nelson 2000). Ammonia nitrogen concentrations met applicable state criteria during all sampling events from 1996 through 2000. However, four pH measurements did not meet Ecology's minimum criterion of 6.5 during sampling during this same sampling period. Three samples exceeded the EPA chronic aluminum criterion (87 µg/L) and two samples exceeded the EPA acute aluminum criterion of 750 µg/L. Mill (Hill) Creek is included on Ecology's 1998 303(d) list as impaired for dissolved oxygen, temperature, and fecal coliform bacteria.

2.2.3.3 Soos Creek

Soos Creek does not always meet applicable state water quality criteria (WAC 173-2-201A) for temperature, pH, dissolved oxygen, copper (chronic), and fecal coliform bacteria. Sites monitored in this subbasin include those on the mainstem as well as numerous tributaries, including Soosette Creek. Streams in the Soos Creek basin are included on Ecology's 1998 303(d) list for dissolved oxygen, temperature, and fecal coliform bacteria.

During sampling, Soos Creek waters were generally clear with elevated fecal coliform bacteria concentrations. Warm summer water temperature and low dissolved oxygen concentrations were recorded during summer sampling. Ammonia nitrogen met applicable state criteria during all sampling events from 1996 through 2000. Most pH measurements were within the state criteria range of 6.5 to 8.5; however, various measurements failed to meet the minimum criterion of 6.5. Sampling indicates these stream waters have low concentrations of metals with the exception of aluminum.

Historical data indicate that water quality in Soosette Creek is fair, and similar to that in Soos Creek. During sampling, stream waters were generally clear with elevated fecal coliform concentrations. Low dissolved oxygen and warm water temperatures were recorded during the warm summer months. Ammonia nitrogen concentrations met applicable state criteria during all sampling events from 1996 through 2000. During this same sampling period, one pH measurement fell below the state's minimum criterion of 6.5.

2.2.3.4 Newaukum Creek

Newaukum Creek does not always meet applicable state criteria (WAC 173-2-201A) for dissolved oxygen, ammonia nitrogen, pH, and fecal coliform bacteria. During sampling, stream waters were generally cool and clear with low dissolved oxygen concentrations. Ammonia nitrogen concentrations met applicable state criteria during all sampling events from 1996 through 2000. However, three pH measurements did not meet Ecology's minimum state criterion of 6.5 during this same sampling period. Three samples exceeded the EPA (2002a) chronic aluminum criterion (87 µg/L) and two samples exceeded the EPA acute aluminum criterion of 750 µg/L. Newaukum Creek is included on the state's 1998 303(d) list for dissolved oxygen, ammonia-nitrogen, and fecal coliform bacteria.

2.2.3.5 Crisp Creek

Crisp Creek (also known as Keta Creek) sampling results indicate that the waters of this stream do not always meet applicable state criteria (WAC 173-2-201A) for temperature, dissolved oxygen, and fecal coliform bacteria. During sampling, stream waters were generally cool. Variable results for fecal coliform bacteria and turbidity have been recorded at two separate sampling sites located approximately one mile apart. The upper site (site F321), located upstream of the Keta Fish Hatchery, consistently exhibited lower turbidity and fecal coliform bacteria concentrations than the lower site (site 0321). Ammonia nitrogen and pH results met applicable state criteria during all sampling events from 1996 through 2000. However, two aluminum samples exceeded the EPA (2002a) chronic criterion (87 µg/L). Crisp Creek is included on Ecology's 1998 303(d) list for fecal coliform bacteria.

3.0 Sampling and Laboratory Analysis Methods

Sample collection, laboratory analysis, and quality control procedures used in this study are described in the Comprehensive Monitoring Program Sampling and Analysis Plan (SAP) prepared for the Green-Duwamish Watershed Water Quality Assessment (GDWQA) project by King County (2002). Site locations, sample types and sampling frequency, sample collection procedures, sample documentation and handing procedures, sampling parameters, laboratory analysis methods, quality control procedures, and data reporting procedures are summarized briefly below.

3.1 Site Locations

During 2003, a total of 17 sites were sampled by King County as part of the GDWQA comprehensive monitoring program. Sampling sites were selected to represent various boundary conditions and land use types within the watershed. Two sites are located on the Green River and five sites are located near the mouths of major streams. The remaining 10 sites are located on tributaries representing the following four categories of land use: forest, agriculture/pasture, low-medium density development, and high density development.

The location of each monitoring site is shown in Figure 5 and described briefly below. Figure 6 presents a simplified schematic showing the relative location of each monitoring site in the Green-Duwamish watershed and the associated monitoring category (i.e., river site, major stream site, or tributary site representing either forest, agriculture/pasture, low-medium density development, or high density development). More detailed information on the location and purpose of each sampling site can be found in the SAP (King County 2002). The 17 sampling site numbers and names, and reason for inclusion in the program include:

- E319 – Upper Green River below Howard Hanson Dam (RM 63.8), representing the lower boundary of the Upper Green River
- A310 – Lower Green River at Fort Dent Park (RM 11.9), representing the lower boundary of the Lower Green River. It should be noted that this site is actually upstream of the confluence with the Black River to avoid perturbations resulting from tidal influences
- 0322 – Newaukum Creek near mouth, representing a major stream basin
- A320 – Soos Creek above fish hatchery, representing a major stream basin
- A315 – Mill (Hill) Creek near mouth, representing a major stream basin
- A317 – Springbrook Creek near mouth, representing a major stream basin

- C317 – Black River Pump Station, representing a major stream basin
- S322 – Newaukum tributary downstream of Weyerhaeuser, representing forest
- F321 – Crisp Creek above fish hatchery, representing forest
- B322 – Newaukum tributary at SE 424th Street ditch, representing agriculture/pasture
- D322 – Newaukum tributary at 236th Avenue SE, representing agriculture/pasture
- Y320 – Soosette Creek, representing low-medium density development
- A330 – Green tributary at Lea Hill, representing low-medium density development
- A326 – Panther Creek, representing low-medium density development
- A307 – Hamm Creek, representing low-medium density development
- I322B – Newaukum tributary at Enumclaw, representing high density development
- B317 – Mill Creek tributary (Springbrook basin), representing high density development

The one site monitored in 2001-2002 but not in 2003 is the Green River tributary in foothills near Tacoma Public Utilities (TPU) diversion (A341), representing forest.

Basin area, impervious area, and land cover characteristics are summarized for each monitoring site in Table 2. Basin areas range from 304 acres for the Newaukum tributary at Enumclaw (I322B) to 134,329 acres for the lower Green River (A310). Effective impervious area ranges from 1 percent for the upper Green River (E319) and the Newaukum tributary downstream of Weyerhaeuser (S322) to 41 percent for the Mill (Springbrook) tributary (B317). Land cover is classified by three types of vegetation (forest, scrub shrub, and grass), three types of development (low, medium, and high intensity), two types of bare surfaces (bare ground/asphalt and bare rock/concrete), and open water.

3.2 Sample Types and Sampling Frequency

Samples were collected during base flow and storm flow conditions. The sample collection protocols and frequency for each type of sampling are described briefly below. More detailed information on this topic can also be found in the SAP for the GDWQA (King County 2002).

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Figure 5. Monitoring sites for the Green-Duwamish watershed water quality assessment, WRIA 9

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Figure 6. Schematic diagram of monitoring sites for the Green-Duwamish watershed water quality assessment

8.5 X 11 Color

Table 2. Basin area, impervious area, and land cover characteristics by site for the Green-Duwamish watershed water quality assessment.

	River		Stream					Forest Tributary		Agriculture Tributary		Low-Medium Development Tributary				High Dev. Tributary	
	E319	A310	0322	A320	A315	A317	C317	S322	F321	B322	D322	Y320	A330	A326	A307	I322B	B317
Basin Area (square miles)	5.7	209.9	27	65.6	12.2	23.4	26.8	2.1	2.3	1.5	1.5	0.8	0.8	1.8	0.8	0.5	0.6
Basin Area (acres)	3,616	134,329	17,304	41,986	7,824	14,988	17,176	1,312	1,455	948	969	486	538	1,142	517	304	406
Effective Impervious Area (acres)	39	6,985	572	2,496	1,376	3,559	4,068	12	27	34	28	53	51	149	60	27	165
Effective Impervious Area (percent)	1	5	3	6	18	24	24	1	2	4	3	11	10	13	12	9	41
Land Cover (percent)																	
Forest	71	42	29	33	14	8	9	76	57	11	22	5	24	13	8	0	0
Scrub/Shrub	10	14	19	13	4	3	3	16	17	17	20	5	6	6	2	2	3
Grass	1	10	27	8	15	9	8	1	6	54	34	15	7	8	17	6	8
Subtotal	82	66	75	54	33	20	19	93	79	83	76	24	37	28	27	8	11
Developed - Low Intensity	4	20	19	29	26	24	24	6	16	13	20	35	36	32	31	35	11
Developed - Medium Intensity	0	8	4	12	20	25	26	0	2	2	3	33	20	28	33	54	23
Developed - High Intensity	1	1	1	1	5	10	10	0	0	1	0	2	1	4	2	1	16
Subtototal	5	29	24	41	51	60	60	6	19	16	23	69	57	63	66	90	50
Bare Ground/Asphalt	0	3	1	3	14	19	19	0	0	1	1	6	7	9	7	2	37
Bare Rock/Concrete	0	0	0	0	1	2	2	0	0	0	0	0	0	0	0	0	3
Subtotal	0	3	1	3	15	21	20	0	0	2	1	6	7	9	7	2	40
Open Water	12	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0

Actual sampling dates for 2003 are presented in Table 3 with the corresponding event identification number assigned by King County. Samples were not collected at all sites for all parameters on these dates; detailed information on sample types is summarized for each site in subsequent sections of this document.

Table 3. Sampling dates for monitoring conducted in 2003 for the Green-Duwamish watershed water quality assessment.

Base Flow		Storm Flow	
Event ID	Sampling Dates	Event ID	Sampling Dates
B8	2/12/03 - 2/13/03	S9	1/3/03 - 1/5/03
B9	4/28/03 - 4/29/03	S10	1/21/03 - 1/23/03
B9A [a]	5/12/03	S11	3/8/03 - 3/10/04
B10	6/8/03 - 6/9/03	S12	10/16/03 - 10/18/03
B11	8/26/03 - 8/27/03	S13	11/17/03 - 11/19/03
B11A [a]	12/19/03		

[a] Field measurements and priority pollutant organics only.

The event designations (i.e., storm versus base flow) by King County shown in Table 3 were not used for defining base and storm events for each sampling site. Base and storm events were designated using hydrologic data as described under Data Management (Section 4.1).

3.2.1 Base Flow Samples

Base flow sampling targeted periods when no precipitation had occurred within at least a 2- to 3-day period, depending on the site, so that streams were sampled after the fall (recession) of the stream hydrograph following a precipitation (storm) event. According to the SAP (King County 2002), base flow sampling was to occur bimonthly (every second month) for a period of one year. A total of seven base flow events were sampled in 2001-2002, which met the project objective (Herrera 2004). An additional six base flow events were sampled from February through December 2003 (see Table 3).

3.2.2 Storm Flow Samples

Storm flow sampling targeted wet periods when at least 0.5 inches of precipitation occurred within a 12-hour period. According to the SAP, between eight and 10 storms were to be sampled during water year 2002, and an unspecified number of storms were to be sampled during water year 2003 depending on the data collected in 2002. To ensure that storm flow sampling occurred throughout the year, no more than two storms were to be sampled each month. A total of eight storms were sampled in 2001-2002 (Herrera 2004), and a total of five storms were sampled in 2003 (see Table 3).

3.3 Sample Collection Procedures

Samples were collected using a combination of manual grab, auto-sequential (series of discrete samples), and auto-composite methods. In addition, field measurements were recorded for selected parameters at each monitoring site. Sample collection and field measurement procedures are described briefly in the subsections to follow. More detailed information on this topic can also be found in the SAP for the GDWQA (King County 2002). Actual sampling procedures used on each sampling date in 2003 are shown in Tables 4 through 10 for the following major categories of parameters: field measurements, conventional parameters, microbiological parameters, nutrients, metals, minerals and priority pollutant organics (see Section 3.5 below for a more detailed discussion of these parameter categories).

3.3.1 Manual Grab Samples

Grab samples were collected according to Environmental Support Services (ESS) Standard Operating Procedure (SOP) # 02-02-13 (Clean Surface Grab Sampling) protocols, which followed U.S. EPA Method 1669 (U.S. EPA 1996). Grab samples were collected while facing upstream to minimize contamination from the sampler or field equipment. Sampling personnel wore multiple layers of PVC gloves and included a pair of shoulder-length gloves to prevent possible contamination from the sampler (King County 2002). Samples for low-level metals analyses were collected using the U.S. EPA "clean hands/dirty hands" technique (U.S. EPA Method 1669). All samples were placed in a cooler with ice and transported to the laboratory for analysis.

Manual grab sampling was the only sampling method used at Soos Creek (A320) and Newaukum tributary at 236th NE (D322). Manual grab sampling was occasionally used at most other sites, and was exclusively used for field measurements, low-level metals, and priority pollutant organics.

3.3.2 Auto-Sequential Samples

For auto-sequential sampling, multiple discrete samples were collected using ISCO 3700 series autosamplers during storm and base flow events. For each storm event, the autosamplers were programmed to collect one sample every four hours for a period ranging from 24 to 40 hours (collecting a total of six to 10 samples) depending on the duration of elevated stream flow. For base flow events, the autosamplers were programmed to collect one sample every four to eight hours for up to a 24-hour base flow event. Results from this type of sampling allows water quality to be examined in relation to the rise, peak, and fall of the storm hydrograph, and to assess variability during base flow events.

The autosamplers were initiated either manually or automatically by a liquid level activator switch for a specific rise in water level. The autosamplers contained 24 bottles and were programmed to fill four bottles for each sample. Thus, a second set of bottles was placed in the autosamplers during a sampling event if more than six samples were collected during the event.

Table 4. Sample types by site for field measurements, Green-Duwamish watershed water quality assessment, 2003.

Event ID	Sample Date	Site E319	Site A310	Site 0322	Site A320	Site A315	Site A317	Site C317	Site S322	Site F321	Site B322	Site D322	Site Y320	Site A330	Site A326	Site A307	Site I322B	Site B317	Total Sites
S9	1/4/2003		S/G	B*/G	S/G	S/G	S/G	S/G	S/G	S/G	S/G	S/G		S/G	S/G		S/G		13
S10	1/22/2003	S/G	S/G	S/G		S/G	S/G	S/G	S/G	S/G	S/G			S/G	S/G				11
B8	2/12/2003	B/G	B/G	B/G	B/G	B/G	B/G	B/G	B/G	B/G	B/G		B/G	B/G	B/G				13
S11	3/9/2003				S/G	S/G		S/G	S/G	S/G	S/G	S/G		S/G	S/G			S/G	10
B9	4/28/2003	B/G			B/G	B/G			B/G	B/G	B/G	B/G		B/G	B/G	B/G			10
B9A	5/12/2003	B/G	B/G	B/G	B/G	B/G	B/G	B/G											7
S?	5/13/2003			B*/G	B*/G	B*/G				B*/G									4
B10	6/9/2003	B/G			B/G	B/G		B/G			B/G	B/G		B/G	B/G	B/G			9
B11	8/26/2003	B/G	B/G	B/G	B/G		B/G	B/G		B/G				B/G	B/G	B/G			10
S12	10/17/2003	S/G		S/G	S/G	S/G						B*/G	S/G	S/G		S/G	B*/G		9
S12	10/18/2003						S/G												1
S13	11/18/2003	S/G		S/G	S/G	S/G		S/G		S/G	S/G	S/G			S/G				9
B11A	12/19/2003	B/G	B/G	B/G	B/G	B/G	B/G	B/G											7
Total Base Flow		6	4	6	7	6	4	5	2	4	3	3	1	4	4	3	1	0	63
Total Storm Flow		3	2	3	4	5	3	4	3	4	4	3	1	4	4	1	1	1	50
Total Samples		9	6	9	11	11	7	9	5	8	7	6	2	8	8	4	2	1	113

S = storm flow event; B = base flow event.
G = grab sample; C = autosampler composite, AS = autosampler sequential.
* indicates a discrepancy between the type of event identified in the field and the type of event designated by hydrologic data analysis (i.e., storm vs. base flow).

Table 5. Sample types by site for conventional parameters, Green-Duwamish watershed water quality assessment, 2003.

Event ID	Sample Date	Site E319	Site A310	Site 0322	Site A320	Site A315	Site A317	Site C317	Site S322	Site F321	Site B322	Site D322	Site Y320	Site A330	Site A326	Site A307	Site I322B	Site B317	Total Sites
S9	1/3/2003	S/C	S/AS	S/AS		S/C				S/C	S/AS			S/C		S/C	S/AS	S/C	10
S9	1/4/2003	B*/C	S/AS	S/AS	S/G	S/C	S/G	S/G	S/G	S/C	S/AS	S/G	S/G	S/C	S/G	S/G	S/AS	S/C	17
S9	1/5/2003		S/AS	S/AS							S/AS						S/AS		4
S10	1/21/2003	B*/C	S/AS	B*/C			B*/C		S/AS		S/AS		B*/C			S/AS	B*/C	B*/C	10
S10	1/22/2003	S/G	S/AS	S/G		S/G	S/G	S/G	S/AS	S/G	S/AS			S/G	S/G	S/AS	S/C	S/C	14
S10	1/23/2003		S/AS						S/AS		S/AS		S/G			S/AS			5
B8	2/12/2003	B/G	B/AS	B/C	B/G	B/G	B/C	B/G	S*/AS	B/G	B/AS		B/G	B/G	B/AS		B/C	B/C	15
B8	2/13/2003		B/AS						B/AS		B/AS				S*/AS				4
S11	3/8/2003	B*/C	S/AS	S/C			B*/C		S/AS		S/AS		B*/C		B*/AS		S/C	B*/C	10
S11	3/9/2003	B*/C	S/AS	S/C	S/G	S/G	S/C	S/G	S/AS	S/G	S/AS	S/G	S/C	S/G	S/AS		S/C	S/G	16
S11	3/10/2003		S/AS						S/AS		S/AS				S/AS				4
B9	4/28/2003	B/G	B/AS	B/C	B/G	B/G	B/C		B/AS	B/G	B/AS	B/G	B/C	B/G	B/AS	B/G	B/C	B/C	16
B9	4/29/2003		B/AS						B/AS		B/AS				B/AS				4
S?	5/13/2003			B*/G	B*/G	B*/G				B*/G									4
B10	6/8/2003	B/C	B/AS	B/C			B/C		B/AS		B/AS				B/AS		B/C	B/C	9
B10	6/9/2003	B/G	B/AS		B/G	B/G		B/G	B/AS		B/AS	B/G		B/G	B/AS	B/G			11
B11	8/26/2003	B/G	B/AS	B/C	B/G		B/C		B/AS	B/G				B/G	B/AS	B/G		B/C	11
B11	8/27/2003		B/AS						B/AS						B/AS				3
S12	10/16/2003	S/C	S/C	S/C			S/AS		S/AS				S/C		S/AS		B*/C	S/C	9
S12	10/17/2003	S/C	S/G	S/C	S/G	S/AS	S/G	S/AS	S/G	S/C			B*/G	S/C		B*/G	S/AS	S/G	14
S12	10/18/2003																S/AS		1
S13	11/17/2003	S/C		S/C		S/AS				S/C	S/AS			B*/C		B*/C	S/AS	S/C	9
S13	11/18/2003	S/C		S/C	S/G	S/AS	S/G	S/G		S/C	S/AS	S/G	S/G	S/C	S/G	S/C	S/AS	S/C	15
S13	11/19/2003					S/AS					S/AS						S/AS		3
Total Base Flow		7	3	8	4	6	5	8	4	6	6	2	3	9	4	7	7	4	93
Total Storm Flow		8	7	13	5	9	4	8	4	8	12	4	3	6	4	6	16	8	125
Total Samples		15	10	21	9	15	9	16	8	14	18	6	6	15	8	13	23	12	218

S = storm flow event; B = base flow event.
G = grab sample; C = autosampler composite, AS = autosampler sequential.
* indicates a discrepancy between the type of event identified in the field and the type of event designated by hydrologic data analysis (i.e., storm vs. base flow).

Table 6. Sample types by site for microbiological parameters, Green-Duwamish watershed water quality assessment, 2003.

Event ID	Sample Date	Site E319	Site A310	Site 0322	Site A320	Site A315	Site A317	Site C317	Site S322	Site F321	Site B322	Site D322	Site Y320	Site A330	Site A326	Site A307	Site I322B	Site B317	Total Sites
S9	1/3/2003	S/C	S/AS	S/AS		S/C				S/C	S/AS			S/C		S/C	S/AS	S/C	10
S9	1/4/2003	B*/C	S/AS	S/AS	S/G	S/C	S/G	S/G	S/G	S/C	S/AS			S/C	S/G	B*/C	S/AS	S/C	15
S9	1/5/2003		S/AS	S/AS							S/AS						S/AS		4
S10	1/21/2003	B*/C	S/AS	B*/C			B*/C		S/AS		S/AS		B*/C			S/AS	B*/C	B*/C	10
S10	1/22/2003	S/G	S/AS	S/C	S/G	S/G	S/G	S/G	S/AS	S/G	S/AS			S/G	S/G	S/AS	S/C	S/C	15
S10	1/23/2003		S/AS	S/G					S/AS		S/AS		S/G			S/AS			6
B8	2/12/2003	B/C	B/AS	B/C	B/G	B/G	B/C	B/G	S*/AS	B/G	B/AS		B/C	B/G	B/AS	B/G	B/C	B/C	16
B8	2/13/2003	B/G	B/AS	B/G			B/G		B/AS		B/AS				S*/AS				7
S11	3/9/2003	B*/G			S/G	S/G										S/G			4
S11	3/10/2003		S/G	S/G			S/G												3
B9	4/28/2003	B/C	B/AS	B/C	B/G	B/G	B/C		B/AS	B/G	B/AS	B/G	B/C	B/G	B/AS	B/G	B/C	B/C	16
B9	4/29/2003	B/G	B/AS	B/G			B/G		B/AS		B/AS				B/AS				7
S?	5/13/2003			B*/G	B*/G	B*/G				B*/G									4
B10	6/8/2003	B/C	B/AS	B/C			B/C		B/AS		B/AS				B/AS		B/C	B/C	9
B10	6/9/2003	B/G	B/AS	B/G	B/G	S*/G	B/G	B/G	B/AS		B/AS	B/G		B/G	B/AS	B/G			13
B11	8/26/2003	B/C	B/AS	B/C	B/G		B/C		B/AS	B/G				B/G	B/AS	B/G		B/C	11
B11	8/27/2003	B/G	B/AS	B/G			B/G		B/AS						B/AS				6
S12	10/16/2003	S/C	S/C	S/C			S/AS		S/AS						S/AS			S/C	7
S12	10/17/2003	S/G	S/C	S/C	S/G	S/G	S/AS		S/AS			B*/G	S/G	S/G	S/AS	S/G		S/C	13
S12	10/18/2003	B*/G		S/G		S/G											S/AS		4
S13	11/17/2003	S/C		S/C		S/AS				S/C	S/AS			B*/C		B*/C	S/AS	S/C	9
S13	11/18/2003	S/C	S/G	S/C	S/G	S/AS	S/G	S/G		S/C	S/AS	S/G	S/G	S/G	S/G	S/C	S/AS	S/C	16
S13	11/19/2003	S/G		S/G		S/AS					S/AS						S/AS		5
Total Base Flow		12	4	8	3	9	5	7	4	5	6	2	3	11	4	6	7	3	99
Total Storm Flow		9	9	13	6	10	5	6	3	7	9	2	1	6	3	3	13	6	111
Total Samples		21	13	21	9	19	10	13	7	12	15	4	4	17	7	9	20	9	210

S = storm flow event; B = base flow event.
G = grab sample; C = autosampler composite, AS = autosampler sequential.
* indicates a discrepancy between the type of event identified in the field and the type of event designated by hydrologic data analysis (i.e., storm vs. base flow).

Table 7. Sample types by site for nutrients, Green-Duwamish watershed water quality assessment, 2003.

Event ID	Sample Date	Site E319	Site A310	Site 0322	Site A320	Site A315	Site A317	Site C317	Site S322	Site F321	Site B322	Site D322	Site Y320	Site A330	Site A326	Site A307	Site I322B	Site B317	Total Sites
S9	1/3/2003	S/C	S/AS	S/AS		S/C				S/C	S/AS			S/C		S/C	S/AS	S/C	10
S9	1/4/2003	B*/C	S/AS	S/AS	S/G	S/C	S/G	S/G	S/G	S/C	S/AS			S/C	S/G	B*/C	S/AS	S/C	15
S9	1/5/2003		S/AS	S/AS							S/AS						S/AS		4
S10	1/21/2003	B*/C	S/AS	B*/C			B*/C		S/AS		S/AS		B*/C			S/AS	B*/C	B*/C	10
S10	1/22/2003	S/C	S/AS	S/C		S/G	S/C	S/G	S/AS	S/G	S/AS			S/G	S/G	S/AS	S/C	S/C	14
S10	1/23/2003		S/AS						S/AS		S/AS		S/G			S/AS			5
B8	2/12/2003	B/C	B/AS	B/C	B/G	B/G	B/C	B/G	S*/AS	B/G	B/AS		B/C	B/G	B/AS		B/C	B/C	15
B8	2/13/2003		B/AS						B/AS		B/AS				S*/AS				4
S11	3/8/2003	B*/C	S/AS	S/C			B*/C		S/AS		S/AS		B*/C		B*/AS		S/C	B*/C	10
S11	3/9/2003	B*/C	S/AS	S/C	S/G	S/G	S/C	S/G	S/AS	S/G	S/AS		S/C	S/G	S/AS		S/C	S/C	15
S11	3/10/2003		S/AS								S/AS				S/AS				3
B9	4/28/2003	B/C	B/AS	B/C	B/G	B/G	B/C		B/AS	B/G	B/AS	B/G	B/C	B/G	B/AS	B/G	B/C	B/C	16
B9	4/29/2003		B/AS						B/AS		B/AS				B/AS				4
S?	5/13/2003			B*/G	B*/G	B*/G				B*/G									4
B10	6/8/2003	B/C	B/AS	B/C			B/C		B/AS		B/AS				B/AS		B/C	B/C	9
B10	6/9/2003		B/AS		B/G	B/G		B/G	B/AS		B/AS	B/G		B/G	B/AS	B/G			10
B11	8/26/2003	B/C	B/AS	B/C	B/G		B/C		B/AS	B/G				B/G	B/AS	B/G		B/C	11
B11	8/27/2003		B/AS						B/AS						B/AS				3
S12	10/16/2003	S/C	S/C	S/C			S/AS		S/AS				S/C		S/AS			S/C	8
S12	10/17/2003	S/C	S/G	S/C	S/G	S/AS	S/G	S/AS	S/G	S/C			B*/G	S/C			S/AS	S/G	13
S12	10/18/2003																S/AS		1
S13	11/17/2003	S/C		S/C		S/AS				S/C	S/AS			B*/C		B*/C	S/AS	S/C	9
S13	11/18/2003	S/C		S/C	S/G	S/AS	S/G	S/G		S/C	S/AS	S/G	S/G	S/C	S/G	S/C	S/AS	S/C	15
S13	11/19/2003					S/AS					S/AS						S/AS		3
Total Base Flow		7	3	8	4	6	5	8	4	6	6	2	3	8	4	6	7	4	91
Total Storm Flow		8	7	13	5	9	4	8	4	8	12	3	1	6	4	5	15	8	120
Total Samples		15	10	21	9	15	9	16	8	14	18	5	4	14	8	11	22	12	211

S = storm flow event; B = base flow event.
G = grab sample; C = autosampler composite, AS = autosampler sequential.
* indicates a discrepancy between the type of event identified in the field and the type of event designated by hydrologic data analysis (i.e., storm vs. base flow).

Table 8. Sample types by site for metals, Green-Duwamish watershed water quality assessment, 2003.

Event ID	Sample Date	Site E319	Site A310	Site 0322	Site A320	Site A315	Site A317	Site C317	Site S322	Site F321	Site B322	Site D322	Site Y320	Site A330	Site A326	Site A307	Site I322B	Site B317	Total Sites
S9	1/3/2003	S/C	S/AS	S/AS		S/C				S/C	S/AS			S/C		S/C	S/AS	S/C	10
S9	1/4/2003	B*/C	S/AS	S/AS	S/G	S/C	S/G	S/G	S/G	S/C	S/AS			S/C	S/G	B*/C	S/AS	S/C	15
S9	1/5/2003		S/AS	S/AS							S/AS						S/AS		4
S10	1/21/2003	B*/C	S/AS	B*/C			B*/C		S/AS		S/AS		B*/C			S/AS	B*/C	B*/C	10
S10	1/22/2003	S/C	S/AS	S/C		S/G	S/C	S/G	S/AS	S/G	S/AS			S/G	S/G	S/AS	S/C	S/C	14
S10	1/23/2003		S/AS						S/AS		S/AS		S/G			S/AS			5
B8	2/12/2003	B/C	B/AS	B/C	B/G	B/G	B/C	B/G	S*/AS	B/G	B/AS		B/G	B/G	B/AS		B/C	B/C	15
B8	2/13/2003		B/AS						B/AS		B/AS				S*/AS				4
S11	3/8/2003	B*/C	S/AS	S/C			B*/C		S/AS		S/AS		B*/C		B*/AS		S/C	B*/C	10
S11	3/9/2003	B*/C	S/AS	S/C	S/G	S/G	S/C	S/G	S/AS	S/G	S/AS		S/C	S/G	S/AS		S/C	S/G	15
S11	3/10/2003		S/AS								S/AS				S/AS				3
B9	4/28/2003	B/C	B/AS	B/C	B/G	B/G	B/C		B/AS	B/G	B/AS	B/G	B/C	B/G	B/AS	B/G	B/C	B/C	16
B9	4/29/2003		B/AS						B/AS		B/AS				B/AS				4
B10	6/8/2003	B/C	B/AS	B/C			B/C		B/AS		B/AS				B/AS		B/C	B/C	9
B10	6/9/2003		B/AS		B/G	B/G		B/G	B/AS		B/AS	B/G		B/G	B/AS	B/G			10
B11	8/26/2003	B/C	B/AS	B/C	B/G		B/C		B/AS	B/G				B/G	B/AS	B/G		B/C	11
B11	8/27/2003		B/AS						B/AS						B/AS				3
S12	10/16/2003	S/C	S/C	S/C			S/AS		S/AS				S/C		S/AS		B*/C	S/C	9
S12	10/17/2003	S/C	S/C	S/C	S/G	S/G	S/AS		S/AS			B*/G	S/G	S/G	S/AS	S/G		S/C	13
S12	10/18/2003																S/AS		1
S13	11/17/2003	S/C		S/C		S/AS				S/C	S/AS			B*/C		B*/C	S/AS	S/C	9
S13	11/18/2003	S/C		S/C	S/G	S/AS	S/G	S/G		S/C	S/AS	S/G	S/G	S/C	S/G	S/C	S/AS	S/C	15
S13	11/19/2003					S/AS					S/AS						S/AS		3
Total Base Flow		6	3	8	3	6	4	8	4	6	6	2	3	8	3	7	7	4	88
Total Storm Flow		8	7	13	5	9	4	8	4	8	12	3	1	6	4	5	15	8	120
Total Samples		14	10	21	8	15	8	16	8	14	18	5	4	14	7	12	22	12	208

S = storm flow event; B = base flow event.
G = grab sample; C = autosampler composite, AS = autosampler sequential.
* indicates a discrepancy between the type of event identified in the field and the type of event designated by hydrologic data analysis (i.e., storm vs. base flow).

Table 9. Sample types by site for minerals, Green-Duwamish watershed water quality assessment, 2003.

Event ID	Sample Date	Site E319	Site A310	Site 0322	Site A320	Site A315	Site A317	Site C317	Site S322	Site F321	Site B322	Site D322	Site Y320	Site A330	Site A326	Site A307	Site I322B	Site B317	Total Sites
S9	1/3/2003	S/C	S/AS	S/AS		S/C				S/C	S/AS			S/C		S/C	S/AS	S/C	10
S9	1/4/2003	B*/C	S/AS	S/AS	S/G	S/C	S/G	S/G	S/G	S/C	S/AS			S/C	S/G	B*/C	S/AS	S/C	15
S9	1/5/2003		S/AS	S/AS							S/AS						S/AS		4
S10	1/21/2003	B*/C	S/AS	B*/C			B*/C		S/AS		S/AS		B*/C			S/AS	B*/C	B*/C	10
S10	1/22/2003	S/C	S/AS	S/C		S/G	S/C	S/G	S/AS	S/G	S/AS			S/G	S/G	S/AS	S/C	S/C	14
S10	1/23/2003		S/AS						S/AS		S/AS		S/G			S/AS			5
B8	2/12/2003	B/C	B/AS	B/C	B/G	B/G	B/C	B/G	S*/AS	B/G	B/AS		B/G	B/G	B/AS		B/C	B/C	15
B8	2/13/2003		B/AS						B/AS		B/AS				S*/AS				4
S11	3/8/2003	B*/C	S/AS	S/C			B*/C		S/AS		S/AS		B*/C		B*/AS		S/C	B*/C	10
S11	3/9/2003	B*/C	S/AS	S/C	S/G	S/G	S/C	S/G	S/AS	S/G	S/AS		S/C	S/G	S/AS		S/C	S/G	15
S11	3/10/2003		S/AS								S/AS				S/AS				3
B9	4/28/2003	B/C	B/AS	B/C	B/G	B/G	B/C		B/AS	B/G	B/AS	B/G	B/C	B/G	B/AS	B/G	B/C	B/C	16
B9	4/29/2003		B/AS						B/AS		B/AS				B/AS				4
B10	6/8/2003	B/C	B/AS	B/C			B/C		B/AS		B/AS				B/AS		B/C	B/C	9
B10	6/9/2003		B/AS		B/G	B/G		B/G	B/AS		B/AS	B/G		B/G	B/AS	B/G			10
B11	8/26/2003	B/C	B/AS	B/C	B/G		B/C		B/AS	B/G				B/G	B/AS	B/G		B/C	11
B11	8/27/2003		B/AS						B/AS						B/AS				3
S12	10/16/2003	S/C	S/C	S/C			S/AS		S/AS				S/C		S/AS		B*/C	S/C	9
S12	10/17/2003	S/C	S/C	S/C	S/G	S/G	S/AS		S/AS			B*/G	S/G	S/G	S/AS	S/G		S/C	13
S12	10/18/2003																S/AS		1
S13	11/17/2003	S/C		S/C		S/AS				S/C	S/AS			B*/C		B*/C	S/AS	S/C	9
S13	11/18/2003	S/C		S/C	S/G	S/AS	S/G	S/G		S/C	S/AS	S/G	S/G	S/C	S/G	S/C	S/AS	S/C	15
S13	11/19/2003					S/AS					S/AS						S/AS		3
Total Base Flow		6	3	8	3	6	4	8	4	6	6	2	3	8	3	7	7	4	88
Total Storm Flow		8	7	13	5	9	4	8	4	8	12	3	1	6	4	5	15	8	120
Total Samples		14	10	21	8	15	8	16	8	14	18	5	4	14	7	12	22	12	208

S = storm flow event; B = base flow event.
G = grab sample; C = autosampler composite, AS = autosampler sequential.
* indicates a discrepancy between the type of event identified in the field and the type of event designated by hydrologic data analysis (i.e., storm vs. base flow).

Table 10. Sample types by site for priority pollutant organics, Green-Duwamish watershed water water quality assessment, 2003.

Event ID	Sample Date	Site E319	Site A310	Site 0322	Site A320	Site A315	Site A317	Site C317	Site S322	Site F321	Site B322	Site D322	Site Y320	Site A330	Site A326	Site A307	Site I322B	Site B317
Halogenated Hydrocarbons																		
S9	1/4/2003	B*/G		S/G	S/G	S/G	S/G											
S10	1/22/2003	S/G		S/G		S/G		S/G										
B9A	5/12/2003	B/G	B/G	B/G	B/G	B/G	B/G	B/G										
B11	8/26/2003	B/G	B/G	B/G	B/G		B/G	B/G										
S12	10/17/2003	S/G		S/G	S/G	S/G												
S12	10/18/2003						S/G											
S13	11/18/2003	S/G			S/G		S/G					S/G		S/G				
B11A	12/19/2003	B/G	B/G	B/G	B/G	B/G	B/G	B/G										
Phenols																		
S9	1/4/2003	B*/G		S/G	S/G	S/G	S/G											
S10	1/22/2003	S/G			S/G							S/G		S/G				
B8	2/12/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				
B9A	5/12/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				
B11	8/26/2003	B/G		B/G		B/G	B/G					B/G		B/G				
S12	10/17/2003	S/G			S/G		S/G							S/G				
S12	10/18/2003					S/G												
S13	11/18/2003	S/G			S/G		S/G					S/G		S/G				
B11A	12/19/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				
Phthalates																		
S9	1/4/2003	B*/G		S/G	S/G	S/G	S/G											
S10	1/22/2003	S/G			S/G							S/G		S/G				
B9A	5/12/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				
B11	8/26/2003	B/G		B/G		B/G	B/G					B/G		B/G				
S12	10/17/2003	S/G			S/G		S/G							S/G				
S12	10/18/2003					S/G												
S13	11/18/2003	S/G			S/G		S/G					S/G		S/G				
B11A	12/19/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				
Polycyclic Aromatic Hydrocarbons (PAHs)																		
S9	1/4/2003	B*/G		S/G	S/G	S/G	S/G											
S10	1/22/2003	S/G			S/G							S/G		S/G				
B9A	5/12/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				
B11	8/26/2003	B/G		B/G		B/G	B/G					B/G		B/G				
S12	10/17/2003	S/G			S/G		S/G							S/G				
S12	10/18/2003					S/G												
S13	11/18/2003	S/G			S/G		S/G					S/G		S/G				
B11A	12/19/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				
Polychlorinated Biphenyls (PCBs)																		
S9	1/4/2003	B*/G		S/G	S/G	S/G	S/G											
S10	1/22/2003	S/G			S/G	S/G						S/G		S/G				
B8	2/12/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				
S11	3/9/2003				S/G		S/G					S/G						
B9A	5/12/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				
B11	8/26/2003	B/G		B/G		B/G	B/G					B/G		B/G				
S12	10/17/2003	S/G			S/G		S/G							S/G				
S12	10/18/2003					S/G												
S13	11/18/2003	S/G			S/G		S/G					S/G		S/G				
B11A	12/19/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				

Table 10 (continued). Sample types by site for priority pollutant organics, Green-Duwamish water quality assessment, 2003.

Event ID	Sample Date	Site E319	Site A310	Site 0322	Site A320	Site A315	Site A317	Site C317	Site S322	Site F321	Site B322	Site D322	Site Y320	Site A330	Site A326	Site A307	Site I322B	Site B317
Miscellaneous Semivolatile Organics																		
S9	1/4/2003	B*/G		S/G	S/G	S/G	S/G											
S10	1/22/2003	S/G			S/G							S/G		S/G				
B8	2/12/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				
S11	3/9/2003				S/G		S/G					S/G						
B9A	5/12/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				
B11	8/26/2003	B/G		B/G		B/G	B/G					B/G		B/G				
S12	10/17/2003	S/G			S/G		S/G							S/G				
S12	10/18/2003					S/G												
S13	11/18/2003	S/G			S/G		S/G					S/G		S/G				
B11A	12/19/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				
Chlorinated Pesticides																		
S9	1/4/2003		S/G	B*/G	S/G	S/G	S/G											
S10	1/22/2003	S/G		S/G		S/G	S/G	S/G										
B8	2/12/2003	B/G	B/G	B/G	B/G	B/G	B/G	B/G										
S11	3/9/2003				S/G	S/G		S/G										
B9A	5/12/2003	B/G	B/G	B/G	B/G	B/G	B/G	B/G										
B11	8/26/2003	B/G	B/G	B/G	B/G		B/G	B/G										
S12	10/17/2003	S/G		S/G	S/G	S/G												
S12	10/18/2003						S/G											
S13	11/18/2003	S/G		S/G	S/G	S/G		S/G										
B11A	12/19/2003	B/G	B/G	B/G	B/G	B/G	B/G	B/G										
Organophosphorus Pesticides																		
S9	1/4/2003	B*/G		S/G	S/G	S/G	S/G											
S10	1/22/2003	S/G			S/G	S/G						S/G		S/G				
B8	2/12/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				
S11	3/9/2003				S/G		S/G					S/G						
B9A	5/12/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				
B11	8/26/2003	B/G		B/G		B/G	B/G					B/G		B/G				
S12	10/17/2003	S/G			S/G		S/G							S/G				
S12	10/18/2003					S/G												
S13	11/18/2003	S/G			S/G		S/G					S/G		S/G				
B11A	12/19/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				
Chlorinated Herbicides																		
S9	1/4/2003	B*/G		S/G	S/G	S/G	S/G											
B9A	5/12/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				
B11	8/26/2003	B/G		B/G		B/G	B/G					B/G		B/G				
S12	10/17/2003	S/G			S/G		S/G							S/G				
S12	10/18/2003					S/G												
S13	11/18/2003	S/G			S/G		S/G					S/G		S/G				
B11A	12/19/2003	B/G		B/G	B/G	B/G	B/G					B/G		B/G				

S = storm flow event; B = base flow event.
G = grab sample; C = autosampler composite, AS = autosampler sequential.
* indicates a discrepancy between the type of event identified in the field and the type of event designated by hydrologic data analysis (i.e., storm vs. base flow).

After sampling, bottles were capped, placed in coolers with ice, and transported to the laboratory for analysis.

At the laboratory, the autosampler bottles were transferred to the appropriate laboratory containers. The four autosampler bottles (representing one sample) were transferred in sequence to the laboratory containers in the following order: the first two bottles were used for filling the conventional and nutrient analysis bottles, the third bottle was used for filling the microbiological analysis bottles, and the fourth bottle was used for the filling the metals analysis bottles. Sample transfer methods are further described in detail in the SAP (King County 2002).

Auto-sequential sampling was the primary sampling method used for the following sampling sites: Lower Green River (A310), Newaukum tributary at Weyerhaeuser (S322), Newaukum tributary at SE 424th (B322), and Panther Creek (A326). Auto-sequential sampling was frequently used for storm flow sampling at Newaukum tributary at Enumclaw (I322B), and occasionally used for storm flow sampling at sites 0322, A315, A317, and A307.

3.3.3 Auto-Composite Samples

For auto-composite sampling, flow-weighted composite samples were collected during storm and base flow events. Sample collection was performed using an ISCO 3700 series autosampler filled with one 15-liter HDPE sample carboy. The autosamplers were triggered either with a timer or by a liquid level activator switch set for a specific stage level rise. A unit sample volume was then collected for each incremental unit of stream flow during the event. Two composite samples were collected if the event extended beyond 24 hours and the two collected samples were analyzed independently. Thus, analytical results for auto-composite samples represent two flow-weighted average concentrations (i.e., event mean concentration) of water samples collected during the sampling event.

The autosampler bottles were fitted with special caps to prevent contamination during the sampling process, and the special caps were replaced with standard caps for transport to the laboratory. The composite samples were transferred to appropriate laboratory containers using a Teflon siphon tube and continuous agitation at the King County Environmental Laboratory. The priority order for filling laboratory containers was: conventionals, microbiological, metals, and lastly nutrients.

Auto-composite sampling was the primary sampling method used for the following sampling sites: Upper Green River (E319), Newaukum Creek (0322), Springbrook Creek (A317), and Mill (Springbrook) tributary (B317). Auto-composite sampling was frequently used at sites F321, Y320, A330, and I322B.

3.3.4 In-stream Field Measurements

In-stream field measurements for water temperature, pH, specific conductance, and dissolved oxygen were recorded prior to or immediately following the collection of samples for laboratory analysis. In-stream field measurements were made using a Hydrolab MiniSonde® or YSI probe. Field sampling equipment were calibrated according to King County Environmental Support Services (ESS) Standard Operating Procedure (SOP) # 02-01-005 within 24 hours of the sampling event.

3.4 Sample Documentation and Handling Procedures

Sample documentation and handling procedures used for the GDWQA are described briefly in the subsections to follow. More detailed information on this topic can also be found in the SAP for the project (King County 2002).

3.4.1 Sample Documentation

In order to ensure that collected samples are properly documented, each sampling location was assigned a unique number for sample identification purposes. Waterproof sample labels (with appropriate numbers) were generated by computer prior to each sampling event. Sampling forms and pre-printed field sheets were completed for each sampling location and each sampling event. Information recorded on field forms included: name of recorder, sample or site number, sample site locator information, date and time of sample collection, results for all field measurements (temperature, pH, dissolved oxygen, and specific conductance), and stream staff gauge height. Field observations and quality control information were also recorded on the data sheets. Field instrument calibration records were recorded in separate instrument logbooks.

3.4.2 Sample Handling

Sample handling procedures outlined in the SAP were used to ensure sample integrity and to provide data of highest quality under the sampling conditions (King County 2002). Accordingly, the following procedures for sample containers were used during sampling:

- All samples were collected or split into pre-cleaned, laboratory-supplied containers.

- All low-level metals analysis sample bottles were double-bagged in ziplock bags in a clean-room environment at the King County Environmental Laboratory, and rebagged after sampling for transport to the laboratory.

- Information was recorded on the sample label that included sample number (or locator), sampling location, collection date, requested analyses, and any chemical used for sample preservation.

After collection, stormwater samples were stored refrigerated at a temperature of approximately 4˚C, or preserved as identified in the SAP (King County 2002). The analytical laboratory held (where practical) any unused sample that had not exceeded its holding time for 30 days after the release of results.

During sampling, all sample bottles were locked in the autosamplers or remained in the custody of sampling personnel (King County 2002). All samples were delivered to Sample Receiving at the laboratory and entered into the Logbook, as described in ESS SOP#01-01-003-001 (Sample Management). The King County Environmental Laboratory performed most of the sample analyses for this project. In instances where sample analyses were performed by a subcontracting laboratory, the associated samples were released according to ESS SOP # 11-02-002-000 (Subcontracting Samples).

3.5 Analytical Parameters

Analytical parameters for base and storm flow monitoring fall into the following seven broad categories: field measurements, conventionals, microbiology, nutrients, metals, minerals, and priority pollutant organics. In addition, samples for priority pollutant organics were collected during selected base and storm flow sampling. The specific analytes for each of these categories are listed below:

- Field measurements – temperature, pH, dissolved oxygen, and specific conductance.

- Conventionals – alkalinity, biochemical oxygen demand, total suspended solids, turbidity, dissolved organic carbon, total organic carbon, and total hardness (which was calculated from calcium and magnesium analyses, but is included as a conventional parameter for this document).

- Microbiology – fecal coliform bacteria, enterococci bacteria, and *E. coli* bacteria.

- Nutrients – ammonia nitrogen, total nitrogen, nitrate and nitrite nitrogen, orthophosphate, and total phosphorus.

- Metals – total and dissolved aluminum, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc.

- Minerals – total and dissolved calcium, iron, magnesium, manganese, potassium, and sodium.

- Priority pollutant organics – base/neutral/acid (semivolatile) organic compounds, chlorinated pesticides/PCBs, organochlorine herbicides, and organophosphorus pesticides.

The number of data points evaluated for each of these parameter categories is presented by monitoring site in Table 11. These numbers represent the typical number of data points for a parameter category, excluding parameters that were analyzed infrequently (e.g., biochemical oxygen demand for conventionals). Also, the numbers in Table 11 do not represent the number of samples analyzed because values for auto-sequential samples were flow-proportionately averaged into one data point for evaluation purposes (see Section 4.1 – Data Management).

3.6 Laboratory Analysis Methods

The laboratory analysis methods used for the GDWQA monitoring program are briefly described below. Two types of detection limits are associated with each chemical analysis method. The method detection limit (MDL) is the minimum concentration that can be detected by the method. The reporting detection limit (RDL) is the minimum concentration that can be reliably quantified. Typically, the RDL is 2 to 5 times higher than the MDL. Only the MDL applies to microbiological parameters. More detailed information on laboratory analysis methods and detection limits can be found in the SAP (King County 2002).

3.6.1 Conventionals

The King County Environmental Laboratory performed all conventional parameter analyses according to Standard Methods (APHA 1995). One exception is that analyses for Biochemical Oxygen Demand (BOD) were performed by the process laboratory at the West Point Treatment Plant. The specific laboratory analysis methods and detection limits for conventional parameters are listed in the SAP (see Table 5 in King County 2002).

3.6.2 Nutrients

The King County Environmental Laboratory performed all nutrient analyses according to Standard Methods (APHA 1995). The specific laboratory analysis methods and detection limits for nutrients are listed in the SAP (see Table 5 in King County 2002).

3.6.3 Microbiology

The King County Environmental Laboratory performed all analyses for microbiological parameters according to Standard Methods (APHA 1995). The specific laboratory analysis methods and detection limits for these parameters are listed in the SAP (see Table 8 in King County 2002).

3.6.4 Metal and Mineral Analyses

All metals and minerals were analyzed according to methods approved by EPA. The King County Environmental Laboratory performed all metals and minerals analyses with the

Table 11. Number of data points (n) by parameter category evaluated for the Green-Duwamish Watershed water quality assessment, 2003.

Site Locator	Field Measurements	Conventional Parameters	Microbiological Parameters	Nutrients	Metals	Minerals
Base Flow						
E319	6	7	12	7	6	6
A310	4	3	4	3	3	3
322	6	8	8	8	8	8
A320	7	4	3	4	3	3
A315	6	6	9	6	6	6
A317	4	5	5	5	4	4
C317	5	8	7	8	8	8
S322	2	4	4	4	4	4
F321	4	6	5	6	6	6
B322	3	6	6	6	6	6
D322	3	2	2	2	2	2
Y320	1	3	3	3	3	3
A330	4	9	11	8	8	8
A326	4	4	4	4	3	3
A307	3	7	6	6	7	7
I322B	1	7	7	7	7	7
B317	0	4	3	4	4	4
Totals	63	93	99	91	88	88
Storm Flow						
E319	3	8	9	8	8	8
A310	2	7	9	7	7	7
0322	3	13	13	13	13	13
A320	4	5	6	5	5	5
A315	5	9	10	9	9	9
A317	3	4	5	4	4	4
C317	4	8	6	8	8	8
S322	3	4	3	4	4	4
F321	4	8	7	8	8	8
B322	4	12	9	12	12	12
D322	3	4	2	3	3	3
Y320	1	3	1	1	1	1
A330	4	6	6	6	6	6
A326	4	4	3	4	4	4
A307	1	6	3	5	5	5
I322B	1	16	13	15	15	15
B317	1	8	6	8	8	8
Totals	50	125	111	120	120	120

Values for auto-sequential samples were flow-proportionately averaged into one data point.

exception of low-level mercury (King County 2002). Low-level mercury analyses were performed by Frontier Geosciences, Inc. of Seattle, Washington using Cold Vapor Atomic Fluorescence (CVAF) (U.S. EPA Method 1631b). The King County Environmental Laboratory analyzed mercury using the less sensitive Cold Vapor Atomic Absorption (CVAA) method (U.S. EPA Method 245.1). All other metals were analyzed by the King County Environmental Laboratory using the following three methods depending on the concentration in the sample:

- Inductively-Coupled Plasma Optical Emission Spectroscopy (ICP-OES) by U.S. EPA Method 200.7

- Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) by U.S. EPA Method 200.8

- Pre-concentration ICP-MS by U.S. EPA Method 1638.

ICP-MS is a more sensitive method and capable of lower detection limits than ICP-OES. Mineral elements (calcium, iron, magnesium, manganese, potassium, and sodium) and other elements were determined by ICP-OES analysis. When a metal (except mineral elements) was not detected by ICP-OES in a sample, subsequent analyses were performed using ICP-MS to achieve a lower detection limit. Only grab samples collected using the clean technique (EPA Method 1669) were analyzed using the most sensitive pre-concentration ICP-MS method for elements not detected using routine ICP-MS. The specific laboratory analysis methods and detection limits for metals and minerals are presented in the SAP (see Table 6 in King County 2002).

3.6.5 Organic Analyses and Detection Limits

Organic analyses were performed by the King County Environmental Laboratory with the exception of chlorinated herbicides, which were analyzed by Severn-Trent-Laboratories (STL-Seattle) of Tacoma, Washington. Laboratory analysis methods and detection limits for organics are listed in the SAP (see Table 7 in King County 2002).

3.7 Quality Control Procedures

Field and laboratory quality control procedures are briefly described below. More detailed information on this topic can be found in the SAP for the GDWQA (King County 2002).

Quality control procedures for field measurements involved the determination of post-deployment calibration drift for the target parameter (except water temperature). Calibration drift was determined by measuring the check standard solution within 12 hours of the final field measurement. Post deployment checks were conducted in the same order used for the initial instrument calibration, and were also conducted before any maintenance or calibrations were performed. Acceptable limits for post-deployment calibration checks are presented in the SAP (see Table 11 in King County 2002).

Quality control procedures for field measurements also involved taking replicate measurements at a minimum frequency of 5 percent or at a minimum of once per day. A field replicate was a separate field sample collected following all the procedures typically done between individual samples. Acceptable limits for field replicate measurements are presented in the SAP (see Table 12 in King County 2002).

Various quality control samples were analyzed at a frequency of one per batch for analysis of conventional parameters, nutrients, metals, and organics. Quality control samples analyzed by the laboratories included processing blanks, replicates (duplicates or matrix spike duplicates), matrix spikes, blank spike duplicates, laboratory control standards or check standards, and surrogates (organics only). Recommended quality control limits for each quality control sample and analytical parameter are presented in the SAP (see Table 10 in King County 2002).

Laboratory quality control measures for microbiological analysis included laboratory duplicates, negative controls, positive controls, and sterility controls (blanks). These measures were used to monitor the performance of each sample analysis batch for each method, as described in the SAP.

3.8 Data Reporting Procedures

Data reporting and record keeping procedures for the GDWQA are described briefly below. More detailed information on this topic can also be found in the SAP (King County 2002).

The King County Environmental Laboratory provides a 30-day turnaround for the analytical data, with the exception of metals, which is up to six months. The laboratory section responsible for each set of analyses produces a narrative describing the contents of their data package, including any notable information of interest to the client. Comprehensive data reports are prepared that consist of spreadsheets of chemical, microbiological, and field data. Where applicable, sample analysis results were presented with a method detection limit (MDL) and a reporting detection limit (RDL). The field and laboratory results (including data flags as noted below) are entered into the King County laboratory management information system (LIMS).

Chemistry, microbiology, and field measurement data underwent standard QA review within each laboratory group according to the Environmental Laboratory QA document and method specific SOPs. Data were subsequently flagged with appropriate laboratory qualifiers, as defined in the SAP (see Table 13 in King County 2002). The laboratory project manager provided a review of the quality control results and provided a summary of this information in a narrative form for project and program managers. All field analysis and sampling records, custody documents, raw laboratory data, data summaries, and case narratives are stored in accordance with King County Environmental Laboratory Policy (King County 2002). A quality assurance memorandum was prepared separately for the metals and organics data (Appendix A).

4.0 Data Management and Analysis Methods

This section describes the data management and analyses methods that were used in the preparation of this data report. This section is organized to include separate subsections for each of the following components of this investigation: data management, computation of summary statistics, comparison to water quality criteria, statistical spatial pattern analysis, and computation of water quality index scores.

4.1 Data Management

In order to perform the required analyses for this report, water quality data collected for GDWQA in 2003 were obtained from the County in an electronic file format that is compatible with the Microsoft Access® software package.

The data received were imported into a Microsoft Access® database, which served as the core data storage library for the project. In order to facilitate the efficient retrieval and analysis of these data, this core database was overlain by an environmental data tracking system called EQuIS®, which allows easy summarization of complex data sets into a variety of formats and presentation modes. Using the Microsoft Access® database and EQuIS® system in combination, separate database queries were made to obtain data for specific analysis tasks related to this assessment. In most cases, the data obtained from these queries were exported to a file format that is compatible with Microsoft Excel® and/or the Statistica® data analysis software package for further processing.

Additional processing of the data was also performed in order to evaluate those samples associated with storm or base flow events. Continuous discharge data collected in 2003 were obtained from King County for stream gauging sites that are associated with the following water 13 quality monitoring sites: Upper Green River (E319); Newaukum Creek (0322); Soos Creek (A320); Mill (Hill) Creek (A315); Springbrook Creek (A317); Newaukum tributary downstream of Weyerhaeuser (S322); Crisp Creek (F321); Newaukum tributary at 236th SE (D322); Soosette Creek (Y320); Panther Creek (A326); Hamm Creek (A307); Newaukum tributary at Enumclaw (I322B); and Mill (Springbrook) tributary (B317).

A computer algorithm was developed for this project to define intervals of the hydrograph that correspond to base and storm flow periods. This algorithm uses a sliding interval to assign a preliminary base flow rate to each hydrograph based on the minimum flow over a 3-day window. It then adjusts the base flow and identifies storm periods based on the following user input variables:

1. Starting base flow rate (cfs) if the initial flow value is missing from the hydrologic record

2. Maximum percent increase per day in base flow

3. Maximum amount (cfs) of increase per day in base flow

4. Minimum percent that the maximum daily discharge must exceed the daily average base flow rate to be categorized as a storm event.

Event delineation was initially performed using daily discharge data and then subsequently performed using hourly discharge data. Input variables were adjusted based on review of the hydrographs and output variables. The final input and output variables are presented in Table 12. An example hydrograph showing event delineation results for Soos Creek (A320) is shown in Figure 7.

Once periods of base and storm flow were defined in the hydrograph using this approach, samples corresponding to these periods were assigned to the same event type in the core project database. In this way, separate analyses could be performed on samples associated with base and storm flow. For sites not having an associated flow gauging site, storm and base designations were based on the type of event identified by field personnel for each sampling date and corresponding event number (e.g., B1 indicates base flow event 1). Sites lacking flow data that were designated by field personnel include: Lower Green River (A310); the Black River (C317); the Newaukum tributary at SE 424th (B322); and the Green tributary at Lea Hill (A330).

The base flow and storm event designation of all samples in the core database were reviewed for consistency with base and storm designations made at the time of sampling. Results from this review are summarized in Tables 4 through 10 for the following major categories of parameters: field measurements, conventionals, microbiology, nutrients, metals, minerals, and organics. These results identified some discrepancies between the base flow and storm event designations using flow data versus those from field observations (i.e., field personnel identified the event as storm flow, but subsequent hydrological analysis revealed the event to be a base flow event). Approximately 7 percent of the data points associated with those sites designated using flow data were assigned a different event type than that identified by field personnel. Percent discrepancies for each parameter category were 6 percent for field measurements, 10 percent for conventionals, 11 percent for nutrients, 9 percent for microbiological parameters, 8 percent for metals, 8 percent for minerals, and 2 percent for organics. Most of the discrepancies were for events designated as base flow using flow data, but identified as storm events by field personnel. Discrepancies were most frequently observed at the Upper Green River below Howard Hanson Dam (E319), which may be due to the regulated nature of the flows at this location (see Tables 4 through 10).

Data processing was also preformed to prevent potential bias in the evaluation of data associated with auto-sequential samples. As noted previously, results from auto-sequential sampling eventually (in a subsequent report) will be examined in relation to the rise, peak, and fall of the storm hydrograph. However, the goal of the evaluation in this report is to characterize water quality over the range of sampled base and storm flow conditions that were present at a particular monitoring site.

Table 12. Input and output variables for delineation of storm events using hourly discharge data in 2003 for the Green-Duwamish watershed water quality assessment.

Water Quality Site Number	Flow Gage Number	Flow Gage Name	Input Variables: Starting Base Flow (cfs)	Maximum Base Flow Increase (%/day)	Maximum Base Flow Increase (cfs/day)	Storm if Exceeds Base Flow by percent	Storm if Exceeds Base Flow by cfs
E319	USGS 5900	Green River Below Howard A. Hanson Dam	157.00	20%	145.0	15%	0.15
A310	No gage	No gage	--	--	--	--	--
0322	USGS 8500	Newaukum Creek Near Black Diamond	8.00	20%	7.0	15%	0.15
A320	54A	Soos Creek near Mouth	20.00	20%	18.0	15%	0.15
A315	41A	Mill Creek at SR 181	8.00	20%	1.5	15%	0.15
A317	03G	Springbrook at O'Grady	7.00	20%	5.0	15%	0.15
C317	No gage	No gage	--	--	--	--	--
S322	44H	Newaukum Creek at 305th	0.10	20%	0.2	15%	0.15
F321	40D	Crisp Creek at Green River Road	2.30	20%	0.5	15%	**1.00**
B322	No gage	No gage	--	--	--	--	--
D322	44G	Green WQA-Agricultural	0.05	20%	0.3	15%	0.15
Y320	54C	Green WQA-Residential (Springwood RDF outflow)	0.05	20%	0.1	15%	0.15
A330	No gage	No gage	--	--	--	--	--
A326	03A	Panther Creek at Talbot Road	0.10	**50%**	0.4	15%	0.15
A307	HA5	Hamm Creek South Fork	0.60	20%	0.3	15%	0.15
I322B	44F	Green WQA-Urban	0.01	20%	0.0	15%	0.15
B317	03F	Mill Creek (north) above Kent Facility	0.60	20%	0.3	15%	**0.80**

Water Quality Site Number	Flow Gage Number	Flow Gage Name	Output Variables: No. of Missing Discharge Values (hours)	No. of Missing Discharge Values (days)	No. of Storm Events	Approx. No. of All Events	Maximum Storm Event Duration (days)	Base Flow Rate Minimum (cfs)	Base Flow Rate Mean (cfs)	Base Flow Rate Maximum (cfs)	Storm Flow Rate Mean (cfs)	Storm Flow Rate Max (cfs)
E319	USGS 5900	Green River Below Howard A. Hanson Dam	11	0.5	58	58	15	195.7	649.1	2,468.0	1,047.6	5,309.9
A310	No gage	No gage	--	--	--	--	--	--	--	--	--	--
0322	USGS 8500	Newaukum Creek Near Black Diamond	0	0.0	55	55	12.9	9.0	31.3	106.8	36.7	193.2
A320	54A	Soos Creek near Mouth	56	2.3	50	50	11.5	18.5	88.9	272.4	72.3	462.2
A315	41A	Mill Creek at SR 181	2,363	98.5	73	100	23.3	0.5	12.6	43.1	13.9	67.8
A317	03G	Springbrook at O'Grady	0	0.0	97	97	10.7	2.7	18.9	75.5	43.4	301.8
C317	No gage	No gage	--	--	--	--	--	--	--	--	--	--
S322	44H	Newaukum Creek at 305th	634	26.4	88	95	18.3	0.3	2.6	7.8	4.9	49.0
F321	40D	Crisp Creek at Green River Road	0	0.0	111	111	5.5	3.5	5.8	10.8	2.6	14.6
B322	No gage	No gage	--	--	--	--	--	--	--	--	--	--
D322	44G	Green WQA-Agricultural	0	0.0	51	51	14	0.0	0.8	4.5	2.8	19.2
Y320	54C	Green WQA-Residential (Springwood RDF outflow)	0	0.0	62	62	13.8	0.0	0.5	1.8	2.8	25.2
A330	No gage	No gage	--	--	--	--	--	--	--	--	--	--
A326	03A	Panther Creek at Talbot Road	2,210	92.1	97	130	8.5	0.0	0.7	4.7	4.1	99.5
A307	HA5	Hamm Creek South Fork	0	0.0	115	115	4.2	0.5	1.0	2.4	1.7	13.8
I322B	44F	Green WQA-Urban	364	15.2	165	172	5.6	0.0	0.1	0.3	1.7	46.8
B317	03F	Mill Creek (north) above Kent Facility	434	18.1	61	64	13.8	0.4	2.0	6.5	15.0	120.4

Bold input values were adjusted from standard values based on review of output data.

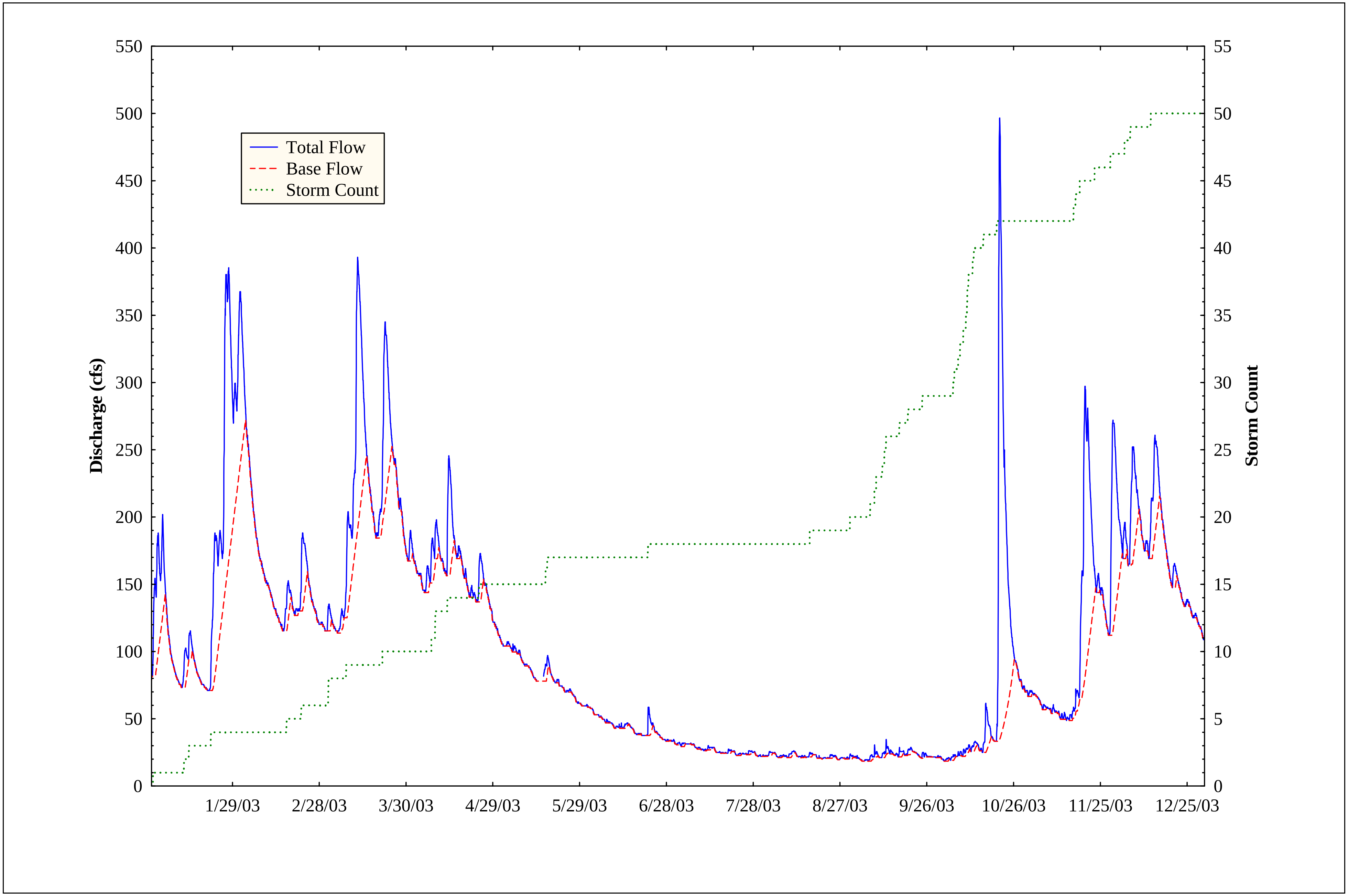


Figure 7. Hydrograph of Soos Creek (A320) peak hourly discharge rates showing delineation of base and storm flow events in 2003.

Analyses performed based on the grab and auto-composite samples are suitable for meeting this goal because each individual sample is typically associated with a single base or storm event. In contrast, there are multiple auto-sequential samples associated with a single base or storm flow event. When analyzed in combination with grab and auto-composite samples, the much larger number of data points from auto-sequential samples (between six and 10 samples per event) would tend to bias any results by giving more weight to the water quality conditions observed during the events sampled with the auto-sequential sampling technique.

In order to resolve this issue, available flow data from each site was used to convert water quality data from auto-sequential samples into a flow-weighted average for each sampled event. Each auto-sequential sample value was multiplied by the flow rate corresponding to the sample time and divided by the sum of the flow rates for the sample set. These corrected values were then summed for the sample set. Where data were undetected, the method detection limit was used in the calculation of the flow-weighted average. In cases where no flow data were available for a particular site, a simple arithmetic average was computed from all auto-sequential samples associated with a particular event. The flow-weighted average or arithmetic average from the auto-sequential samples was used as one data point in the evaluations for this report.

4.2 Computation of Summary Statistics

In order to characterize water quality conditions in the Green-Duwamish watershed, data obtained from the database queries described above were imported into Microsoft Excel® and/or the Statistica® data analysis software package. These software packages were then used to calculate the following summary statistics for each site based on the data collected in 2003:

- Number of samples
- Arithmetic mean
- Geometric mean
- Median
- Minimum
- Maximum
- 10th percentile
- 25th percentile
- 75th percentile
- 90th percentile
- Standard deviation
- Quartile range (i.e., the 75th percentile minus the 25th percentile)
- Lower 95 percent confidence interval
- Upper 95 percent confidence interval
- Percentage of detected samples (for selected parameters).

For all parameters, separate calculations were made for storm and base flow samples from each monitoring site. These statistics were also computed using the storm and base flow data for all monitoring sites combined. Where undetected values were present in the data, the method detection limit was used in all calculations. The computed summary statistics were subsequently compiled in one table for each parameter. Tables of summary statistics are presented in a separate appendix for each parameter category (Appendices B through O).

In addition to these tabular data summaries, the data were also presented in graphical summaries using "box and whisker" plots. Each of these plots presents the following information: the 10^{th} and 90^{th} percentiles of the data as the lower and upper whiskers, respectively; the 25^{th} and 75^{th} percentiles of the data as the lower and upper boundaries of the box, respectively; and the median as the point in the box. Separate box plots were generated for each site using the associated base and storm flow samples, respectively. These plots are presented together in subsequent sections of this report to facilitate comparisons of monitoring data between the individual monitoring sites and between the different event types.

4.3 Comparison to Water Quality Criteria

In order to identify those subbasins/streams in the Green-Duwamish watershed exhibiting impaired water quality, data from each monitoring site were compared to various regulatory water quality criteria in the following order of priority:

1. Water Quality Standards for Surface Waters of the State of Washington (WAC 173-201A amended July 1, 2003)

2. National Recommended Water Quality Criteria: 2002 (U.S. EPA 2002a)

3. Ambient Water Quality Criteria Recommendations: Rivers and Streams in Nutrient Ecoregion II (U.S. EPA 2000)

4. Ambient Water Quality Criteria for Bacteria – 1986 (U.S. EPA 1986).

Surface water quality standards for the state of Washington vary depending on the specific designated uses that have been established for the water body in question. Designated uses that are applicable to the monitoring sites in this study are presented in Table 13, and the applicable criteria are presented in Table 14. Table 15 presents applicable water quality criteria for bacteria, nutrients, and toxic substances that are recommended by EPA (1986, 2000, 2002a) but are not regulated by Washington State. Comparisons to the EPA toxic substances criteria were based on criteria established for the protection of aquatic life and were not based on criteria for protection of human health (for consumption of water and/or organisms).

Most toxic substances have separate criteria for acute and chronic impacts to aquatic life. In these cases, chronic criterion were used when making comparisons to data from base flow sampling and acute criteria were used for storm flow data. Criteria for some toxic substances vary with other parameters such as hardness or pH. These criteria were calculated for each sample and compared to the measured toxic substances concentrations, but only criteria for typical parameter values are presented in Tables 13 and 14.

Table 13. State of Washington designated uses (WAC 173-201A) for monitoring sites associated with the Green-Duwamish water quality assessment.

Site Name	Aquatic Life Designated Use	Water Contact Recreation Designated Use
Lower Green River (A310)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Upper Green River (E319)	Salmon and Trout Spawning, **Core** Rearing, and Migration	Extraordinary Primary Contact Recreation
Hamm Creek (A307)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Black River (C317)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Springbrook Creek (A317)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Panther Creek (A326)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Mill (Springbrook) tributary (B317)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Mill (Hill) Creek (A315)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Green tributary at Lea Hill (A330)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Soos Creek (A320)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Soosette Creek (Y320)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Crisp Creek (F321)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Newaukum Creek (0322)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Newaukum tributary at 236th SE (D322)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Newaukum tributary at SE 424th (B322)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Newaukum tributary at Enumclaw (I322B)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation
Newaukum tributary downstream of Weyerhaeuser (S322)	Salmon and Trout Spawning, **Noncore** Rearing, and Migration	Primary Contact Recreation

Source: WAC 173-201A

Table 14. Water quality criteria for surface waters of the state of Washington used for comparison to 2003 data collected for the Green-Duwamish watershed water quality assessment.

Aquatic Life Criteria in Freshwater		
	Core Rearing	Noncore Rearing
Temperature	Shall not exceed 16.0°C	Shall not exceed 17.5°C
Dissolved oxygen	Shall exceed 9.5 mg/L	Shall exceed 8.0 mg/L
pH	Shall be within the range of 6.5 to 8.5	Shall be within the range of 6.5 to 8.5
Water Contact Recreation in Freshwater		
	Extraordinary Primary Contact Recreation	Primary Contact Recreation
Fecal coliform bacteria	Geometric mean shall not exceed 50 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean values exceeding 100 colonies/100 mL.	Geometric mean shall not exceed 100 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean values exceeding 200 colonies/100 mL.
Trace Metals in Freshwater		
	Acute Criteria	Chronic Criteria
Arsenic, dissolved	360 μg/L [c]	190 μg/L [d]
Cadmium, dissolved	1.3 μg/L[c] at median hardness [e]	0.7 μg/L [d] at median hardness [e]
Chromium, total	254 μg/L[c] at median hardness [e]	119 μg/L [d] at median hardness [e]
Copper, dissolved	7 μg/L[c] at median hardness [e]	7.5 μg/L [d] at median hardness [e]
Lead, dissolved	22.9 μg/L[c] at median hardness [e]	1.5 μg/L [d.]
Mercury, dissolved	2.1 μg/L [c]	none
Mercury, total	none	0.012 μg/L [d]
Nickel, dissolved	640 μg/L [c] at median hardness [e]	104 μg/L [d] at median hardness [e]
Selenium, total	20 mg/L [c]	5 μg/L [d]
Silver, dissolved	0.7 μg/L [a] at median hardness [e]	none
Zinc, dissolved	51.6 μg/L [c] at median hardness [e]	69.2 μg/L [d] at median hardness [e]
Organic Substances in Freshwater		
	Acute Criteria	Chronic Criteria
Aldrin+Dieldrin	2.5 μg/L [a]	0.0019 μg/L [b]
Ammonia (total)	19.7 mg/L assuming salmonids are present and typical values for temperature (15°C) and pH (7.0).	2.1 mg/L assuming salmonids are present and typical values for temperature (15°C) and pH (7.0).
Chlordane	2.4 μg/L [a]	0.0043 μg/L [b]
Chlorpyrifos	0.083 mg/L [c]	0.041 mg/L [d]
DDT (and metabolites)	1.1 μg/L [a]	0.001 μg/L [b]
Endosulfan (I or II)	0.22 μg/L [a]	0.056 μg/L [b]
Endrin	0.18 μg/L [a]	0.0023 μg/L [b]
Heptachlor	0.52 μg/L [a]	0.0038 μg/L [b]
Hexachlorocyclohexane (Lindane)	2.0 μg/L [a]	0.08 μg/L [b]
Parathion	0.065 μg/L [c]	0.013 μg/L [d]
Pentachlorophenol	9.07 μg/L [c] at pH 7.0	5.72 μg/L [d] at pH 7.0
Polychlorinated biphenyls, total	2.0 μg/L [b]	0.014 μg/L [b]

Source: WAC 173-201A.
[a] An instantaneous concentration not to be exceeded at any time.
[b] A 24-hour average not to be exceeded.
[c] A 1-hour average concentration not to be exceeded more than once every three years on the average.
[d] A 4-day average concentration not to be exceeded more than once every three years on the average.
[e] Criterion varies with hardness. The acute criterion presented is based on the median hardness value of 39.1 mg/L as $CaCO_3$ for all stations during storm flow. The chronic criterion presented is based on the median hardness value of 61.5 mg/L as $CaCO_3$ for all stations during base flow.
mg/L: milligram/liter. μg/L: microgram/liter. mL: milliliter. C: Celsius.

Table 15. U.S. EPA national recommended water quality criteria for bacteria, nutrients, and toxic substances in freshwaters that are not regulated by Washington state.

Indicator Bacteria in Freshwater [a]		
	Criteria	
Enterococci	Geometric mean shall not exceed 33 colonies/100 mL	
E. coli	Geometric mean shall not exceed 126 colonies/100 mL	
Nutrients in Rivers and Streams [b]		
	Criteria	
Nitrate+nitrite nitrogen	0.26 mg/L	
Total nitrogen	0.24 mg/L	
Total phosphorus	0.0195 mg/L	
Toxic Substances in Freshwater [c]		
	Acute (CMC) Criteria	Chronic (CCC) Criteria
Aluminum, total	750 µg/L	87 µg/L
Camphechlor (toxaphene)	0.73 µg/L	0.0002 µg/L
Heptachlor epoxide	0.52 µg/L	0.014 µg/L
Malathion	none	0.1 µg/L
Methoxychlor	none	0.03 µg/L
Iron	none	1 mg/L

[a] Source: U.S. EPA 1986.
[b] Source: U.S. EPA 2000; 25th percentile for Puget Sound lowlands subecoregion.
[c] Source: U.S. EPA 2002a.
CMC: criterion maximum concentration.
CCC: criterion continuous concentration.
µg/L: microgram/liter.
mg/L: milligram/liter.
mL: milliliter.

The EPA nutrient criteria presented in Table 15 for phosphorus and nitrogen were developed for the protection of recreation and aquatic life uses in rivers and streams (U.S. EPA 2000). These criteria are intended to address the adverse effects of excessive nutrients in streams and rivers, and are empirically derived to represent conditions of surface waters that have been minimally impacted by human activities and are protective of recreational and aquatic life uses (U.S. EPA 2000). However, Lee and Jones-Lee (2002) and DiToro and Thuman (2001) have noted that the EPA nutrient criteria approach has neglected to link the cause (high nutrient concentrations) to the effects (biological and water quality impacts). Furthermore, the EPA nutrient criteria approach implies that 75 percent of the waterbodies in an ecoregion will not meet the nutrient criteria because they are equivalent to the median of 25th percentiles for four seasons using all data compiled from an ecoregion.

The EPA criteria presented in Table 15 for enterococci and *E. coli* bacteria assume summer bathing conditions (U.S. EPA 1986), which would presumably represent steady state, dry weather. However, these criteria were applied to both the storm and base flow data in this assessment.

Results from these comparisons were summarized based on the percentage of samples from each site that exceeded the applicable or recommended criterion for a given parameter. Nondetected parameters having a detection limit greater than the applicable criterion were excluded from these calculations. The results from these calculations were tabulated along with the summary statistics described above and are presented in Appendices B through O.

4.4 Spatial Pattern Analysis

Statistical spatial pattern analyses were performed on the GDWQA data collected in 2003 in order to meet the following study objectives:

1. Detect significant longitudinal patterns in water quality along the main stem of the Green River.

2. Determine whether there are significant differences in water quality among the five major streams that discharge to the Green River.

In order to meet the first study objective, water quality data (excluding organics) from the Upper Green River (E319) and Lower Green River (A310) were compared using a Mann-Whitney test, which is a nonparametric analog to the t test but does not require a normal distribution of data (Helsel and Hirsch 1992, Zar 1984). Results from this test indicate whether there was a significant increasing or decreasing pattern among these sites for each parameter, or no change at all. Statistical significance for this test was assessed at $\alpha = 0.05$.

The second study objective was evaluated using a statistical comparison of results for sites located near the mouths of the following four major streams: Springbrook Creek (Black River) (A317 and C317, respectively), Mill Creek (A315), Soos Creek (A320), and Newaukum Creek (0322). Specifically, the data (excluding organics) were compared using a Kruskal-Wallis (nonparametric) analysis of variance (ANOVA) to determine if there was a significant difference in water quality among these sites (Helsel and Hirsch 1992, Zar 1984). If a significant difference was detected, a nonparametric multiple comparison test was conducted to determine which monitoring sites were significantly different from the others (Zar 1984). (This test is calculated in the same manner as the Tukey test except the rank sums of the data are used instead of the means. This test uses the overall error rate for the test as opposed to the error rate for each pairwise comparison.) Statistical significance for these tests was assessed at $\alpha = 0.05$.

Results of these spatial pattern analysis tests are presented in Appendix P. These results are discussed in detail for each parameter in Section 5.2.

4.5 Computation of Water Quality Index Rating

In order to summarize water quality patterns for the GDWQA and facilitate comparisons between the monitoring sites, available data from 2003 were used to calculate a Water Quality

Index (WQI) for each site using protocols developed by Ecology (2002a; 2002b). The WQI is a unitless number ranging from 1 to 100 with higher numbers indicating better water quality. This index is calculated using data for the following suite of parameters: temperature, pH, fecal coliform bacteria, dissolved oxygen, total suspended solids, turbidity, total phosphorus, and total nitrogen. Constituent scores from these individual parameters are combined and the results aggregated over time to produce a single yearly score for each monitoring site. This score can serve as the basis for comparing water quality between monitoring sites or for assessing patterns at individual sites over time.

In general, the WQI provides an indication as to whether water quality is adequate for supporting the beneficial uses of a given waterbody as defined in WAC 173-201A. Thus, for temperature, pH, fecal coliform bacteria, and dissolved oxygen, the WQI expresses results relative to applicable water quality criteria for these parameters (see Table 12) that have been promulgated to maintain beneficial uses. For nutrient and suspended sediment measures, where criteria have not been established by Ecology, results are expressed relative to expected conditions in a given ecoregion as determined by U.S. EPA (2000). Sites scoring 80 and above likely meet expectations for water quality and are of "lowest concern," while scores ranging from 40 to 80 indicate "marginal concern," and water quality at sites with scores below 40 are likely not meeting expectations and are of "highest concern" (Ecology 2002a; 2002b).

It should be noted that the WQI contains less information by design than the raw data it summarizes. Thus, it is most useful for making broad comparisons between sites and answering general questions about the water quality in each stream (Ecology 2002a; 2002b). The WQI is less suited to answering site-specific questions regarding water quality because this typically requires detailed analyses of the water quality data. There are at least two reasons that the WQI may fail to accurately communicate water quality information. First, the index, like most indices, is based on a pre-identified suite of water quality parameters. Therefore, a particular site may receive a good WQI score, and yet have water quality that is impaired by parameters not included in the index. Second, aggregation of data may mask short-term water quality problems. It follows that a satisfactory WQI at a particular site does not necessarily mean that water quality was always satisfactory. A good score only indicates that poor water quality is not a chronic problem. Due to these considerations, the WQI was only employed in this analysis to summarize broad patterns in the data.

5.0 Data Evaluation and Results

This section summarizes the data collected for the GDWQA in 2003. Precipitation amounts for the monitoring period relative to historical precipitation data are evaluated here along with the water quality monitoring results for each of the following major parameter categories: field measurements, conventionals, microbiological parameters, nutrients, metals, and priority pollutant organics.

5.1 Precipitation Data

In order to provide some context for interpreting the water quality data collected in 2003 for the GDWQA, monthly and annual precipitation totals from this period were compiled and compared to historical precipitation totals. Data for the following King County rain gauges in the Green-Duwamish watershed (see Figure 5) were compiled for this analysis:

- Lower Green River (gauge 32U)
- Soos Creek (gauge 54V)
- O'Grady Creek (gauge 40U)
- Covington Creek (gauge 09U).

Monthly and annual precipitation totals for each of these gauges are summarized in Table 16 for 2003, and the historical period of record. Monthly precipitation totals in 2003 are compared to the 25th and 75th percentiles of historical data in Figures 8a and 8b for the four rain gauges. These data indicate that precipitation totals measured in January, March, and October of 2003 were generally higher than historical averages, and precipitation totals measured in February and May through August of 2003 were substantially lower than historical averages. Thus, the summer of 2003 was unusually dry. As indicated in Table 3, sampling included in this project report was initiated in January of 2003 and ended in December of 2003.

5.2 Quality Assurance Review Summary

Chemistry, microbiology, and field measurement data underwent standard QA review within each laboratory group according to the Environmental Laboratory QA document and method specific SOPs. Data were subsequently flagged with appropriate laboratory qualifiers, as defined in the SAP (see Table 13 in King County 2002). The laboratory project manager provided a review of the quality control results and provided a summary of this information in a narrative form for project and program managers. The purpose of this review is to provide the project and program managers with the necessary level of information to interpret the data. Technical memoranda were prepared that summarize field sampling, analytical work, and interpretation of QC results. All field analysis and sampling records, custody documents, raw laboratory data, data summaries, and case narratives are stored in accordance with King County Environmental Laboratory Policy (King County 2002).

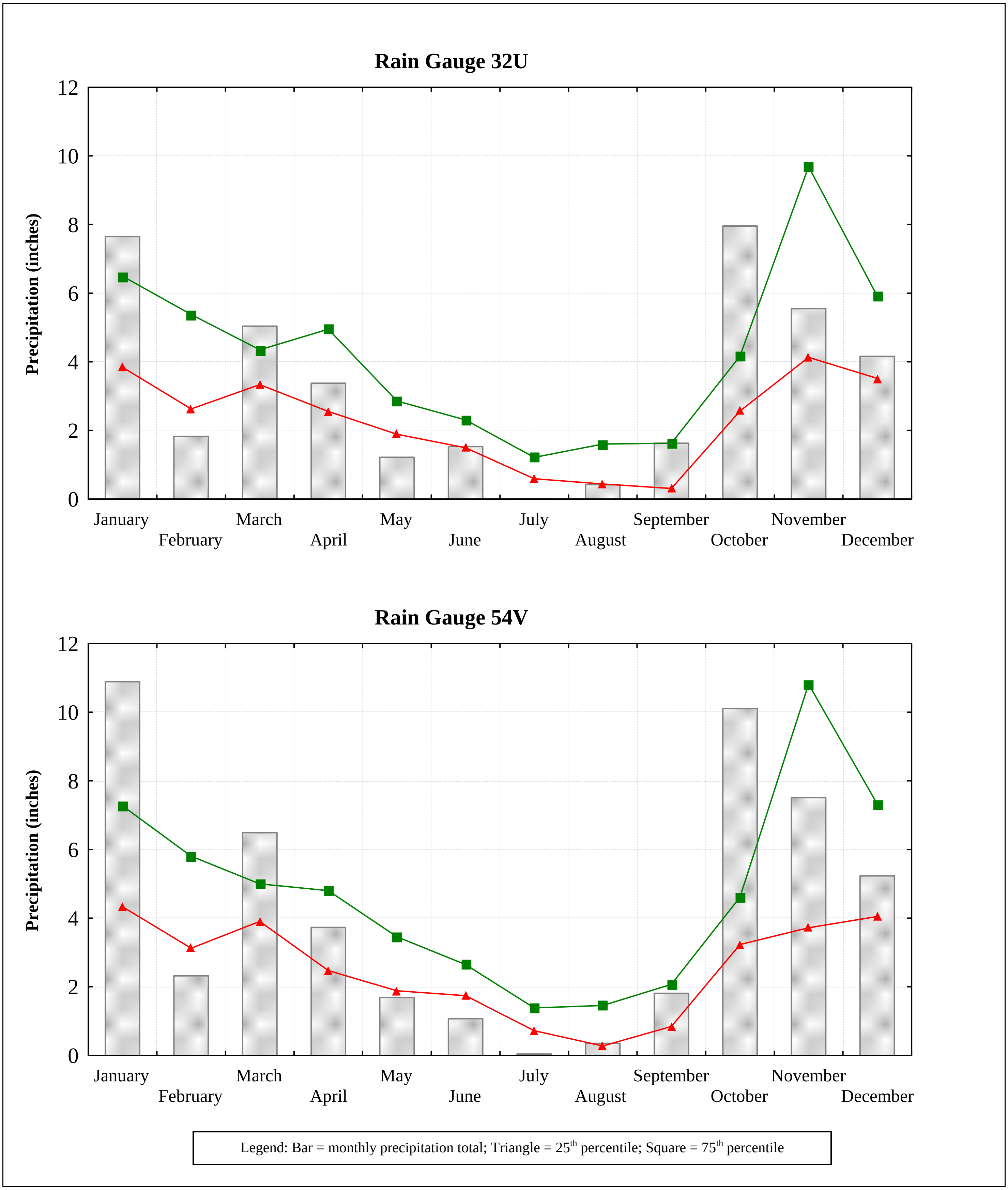
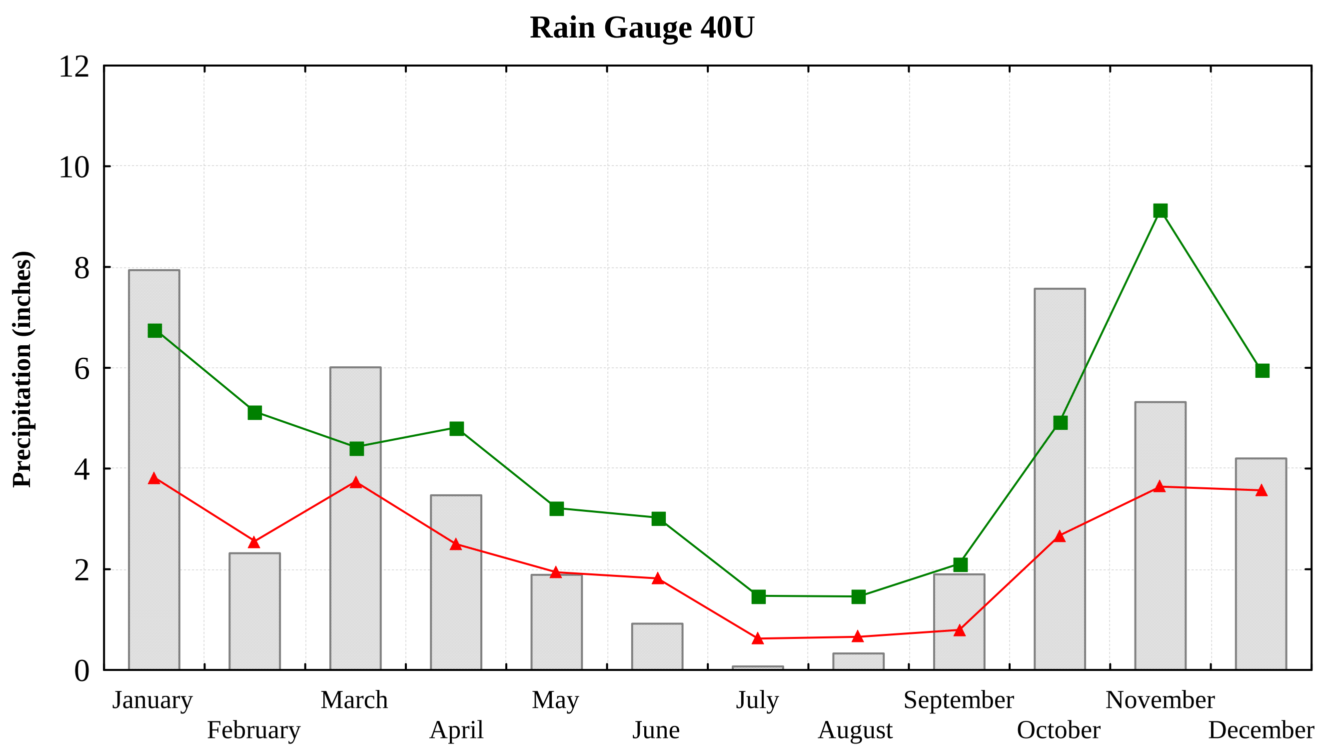
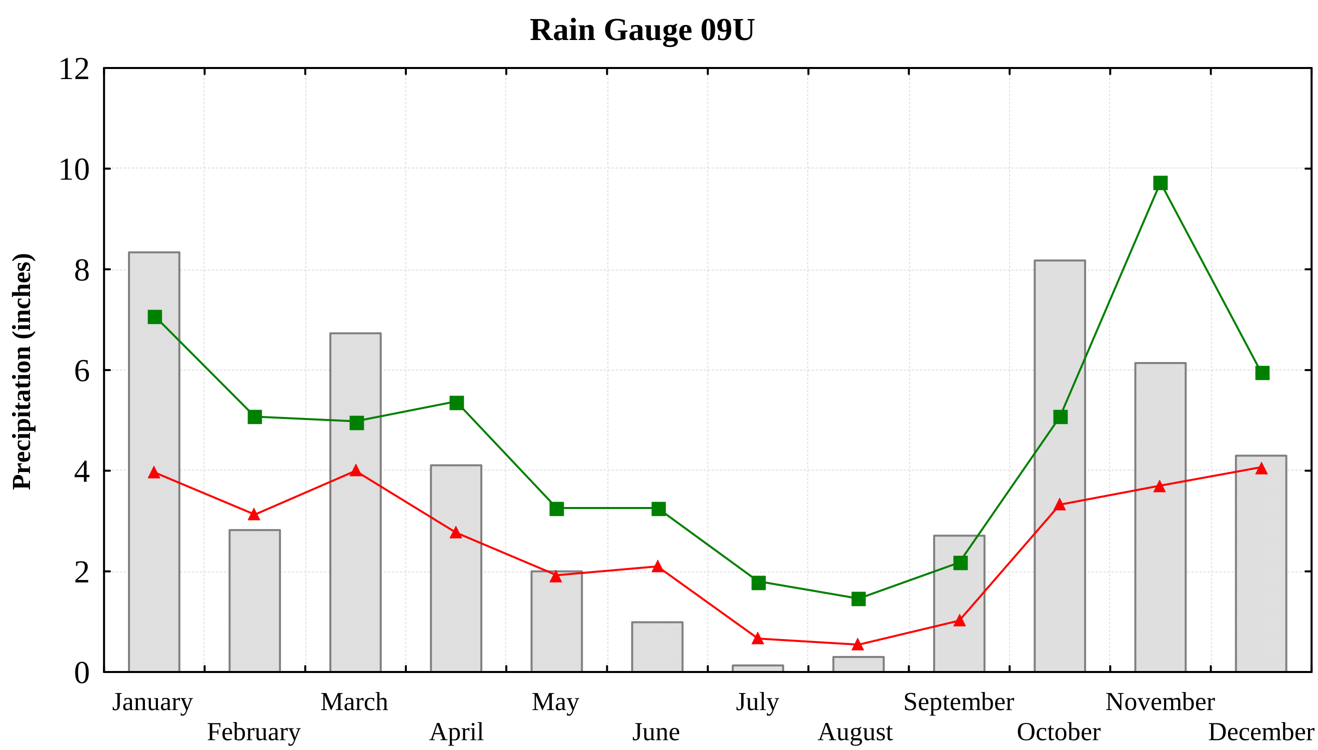


Figure 8a. Monthly precipitation totals for 2003 from rain gauges 32U and 54V in the Green-Duwamish Watershed compared to historical statistics.





Legend: Bar = monthly precipitation total; Triangle = 25th percentile; Square = 75th percentile

Figure 8b. Monthly precipitation totals for 2003 from rain gauges 40U and 09U in the Green-Duwamish Watershed compared to historical statistics.

Table 16. Monthly and annual precipitation totals (in inches) for 2003 from rain gauges in the Green-Duwamish Watershed compared to historical totals.

	Lower Green River (gauge 32U)		Soos Creek (gauge 54V)		O'Grady Creek (gauge 40U)		Covington Creek (gauge 09U).	
	Historical [a]	2003	Historical [b]	2003	Historical [b]	2003	Historical [b]	2003
January	5.41	**7.65**	5.78	**10.89**	5.12	**7.94**	5.58	**8.34**
February	3.96	*1.83*	4.57	*2.32*	3.98	*2.32*	4.32	*2.82*
March	3.91	**5.04**	4.39	**6.49**	4.04	**6.01**	4.35	**6.73**
April	3.58	3.38	3.80	3.73	3.69	3.47	4.12	4.11
May	2.30	*1.22*	2.58	*1.69*	2.53	*1.89*	2.82	2.00
June	2.04	*1.53*	2.25	*1.07*	2.43	*0.92*	2.69	*0.99*
July	0.97	*0.01*	1.04	*0.04*	1.14	*0.07*	1.39	*0.13*
August	0.91	*0.42*	0.93	0.35	1.03	*0.33*	1.10	*0.30*
September	1.01	1.63	1.45	1.81	1.56	1.9	1.56	**2.71**
October	3.42	**7.96**	3.96	**10.11**	3.71	**7.57**	4.23	**8.18**
November	6.59	5.55	7.22	7.51	6.39	5.32	6.90	6.14
December	5.05	4.16	6.44	5.23	5.21	4.2	5.66	4.30
Total	39.12	40.38	44.42	**51.24**	40.82	41.94	44.72	46.75

[a] Based on average monthly and annual precipitation totals measured over the period from 1989 through 2002.
[b] Based on average monthly and annual precipitation totals measured over the period from 1992 through 2002.
Values in *italics* are below the 25th percentile value from the historical monthly or annual precipitation totals.
Values in **bold** are above the 75th percentile value from the historical monthly or annual precipitation

Data were flagged as estimated (and detected) values at the following frequency: 1 percent of the in-stream measurement data, 7 percent of the conventionals data, 9 percent of the microbiological data, and 8 percent of the nutrient data. All estimated values were used for the water quality data evaluation.

A quality assurance review memorandum was prepared separately for the metals and organics data (Appendix A). These memoranda include review of data for three sampling events in 2002 that are not evaluated for this report. Samples for these three events were collected in November and December of 2002, while this report only considers data from the 2003 calendar year. Quality assurance review findings of the 2003 metals and organics data are summarized below.

The quality assurance review memorandum for the metals (and minerals) data summarizes quality control issues associated with each metal and sampling event for the following quality control elements: completeness; field contamination; laboratory contamination; accuracy, precision, and bias; and sample handling. Data were complete for all metals identified in the SAP (King County 2002) and evaluated for this report, but data were not complete for many of the additional metals analyzed (which included antimony, barium beryllium, cobalt, molybdenum, thallium, and vanadium).

Low recovery of matrix spikes was infrequently noted for total aluminum in project samples and field blanks. Field blank contamination was frequently noted for total chromium and low-level mercury analyses, and was infrequently noted for total copper and total zinc. Filter blank contamination was frequently noted for dissolved chromium and dissolved zinc. Finally, many sample values were not preserved or filtered within the recommended limit of 24 hours. The laboratory flagged dissolved metals values with a B for values within 10 times the filter blank value, and with an H for sample handling issues. Data were not flagged for issues associated with field blanks or matrix spikes. Approximately 35 percent of the metals data were flagged as estimated (and detected) values.

The quality assurance review memorandum for the organics data summarizes quality control issues associated with method blanks, spike blanks, matrix spikes, and surrogate compounds (see Appendix A). The following four phthalate compounds were detected in every method blank: butylbenzylphthalate, bis(2-ethylhexyl)phthalate, diethylphthalate, and di-n-butylphthalate. The laboratory recommended raising the method detection limits by a factor of 10 for these four compounds, which would have resulted in undetected values for all but two sample values (see Appendix A). However, the associated phthalate values were flagged with a B in the database rather than changed to undetected values at a raised detection limit.

Spike blank recoveries occasionally exceeded the upper control limits for the following compounds discussed in this report: 4-chloro-3-methylphenol, phorate, methyl parathion, 1,4-dichlorobenzene, endrin, and disulfoton. No data were flagged because these compounds were not detected in any of the samples. Matrix spike recoveries occasionally exceeded the upper control limits for the following compounds: 4-chloro-3-methylphenol, pentachlorophenol, methyl parathion, and endrin. However, the only compound detected in associated samples was pentachlorophenol. Finally, the recovery of one surrogate compound (d5-phenol) in four storm flow samples from sites A320, A315, C317, and A315 slightly exceeded the upper control limit (by between 1 and 6 percent), and no data were flagged based on this surrogate recovery. The recovery of one surrogate compound (2,4,5,6-tetrachloro-m-xylene) from one storm flow sample was below the lower control limit by 1 percent from site A315, and no data were flagged based on this surrogate recovery.

5.3 Water Quality Data

This section summarizes results from water quality sampling conducted in 2003 for the GDWQA. The presentation of these results is organized into separate subsections for each of the following parameter categories:

- Field measurements
- Conventional parameters
- Microbiological parameters
- Nutrients
- Metals
- Minerals
- Priority pollutant organics.

Results are discussed below for each water quality parameter. This discussion begins with a brief overview of the purpose and importance of the parameter, and then summarizes any significant findings from the Habitat Limiting Factors and Reconnaissance Assessment Report (Kerwin and Nelson 2000). Results for base and storm flow sampling are discussed for the two Green River sites, the five major stream sites, and finally the 10 tributary sites. To support these discussions, tabular summaries of the data are provided in a separate appendix for each parameter category with a separate appendix for each group of priority pollutant organics (Appendices B through O). Results of the statistical analyses are presented in Appendix P. Graphical data summaries are presented below for each monitoring parameter (excluding organics). Finally, results of the computed WQI index scores for each site are presented and discussed at the end of this section.

5.3.1 In-stream Field Measurements

In-stream field measurement data collected in 2003 for the GDWQA are summarized below. Summary statistics for these parameters are also presented in Appendix B and results from associated statistical spatial pattern analyses are presented in Appendix P. Field measurement parameters include:

- Temperature
- Dissolved oxygen
- pH
- Specific conductance.

5.3.1.1 Temperature

In-stream water temperature data were collected during base flow and storm flow sampling and represent instantaneous temperature measurements. State water quality criteria for temperature (see Table 14) are based on a seven-day average daily maximum (7-DADMax). The maximum allowable 7-DADMax is 16.0°C in core salmonid rearing waters and 17.5°C in noncore salmonid rearing waters (WAC 173-201A). Waterbodies in this monitoring study that are on the Ecology 1998 303(d) water quality limited list for temperature are: the Green River (upper and lower segments), Springbrook Creek, Mill (Hill) Creek, and Soos Creek. King County (2000) identified high temperatures as a possible factor contributing to salmonid decline in Crisp Creek, Soos Creek, Soosette Creek, Mill (Hill) Creek, Springbrook Creek, and the Lower Green River. However, the county determined that temperature was not likely a factor in salmonid decline in Newaukum Creek and the Middle Green River.

King County is conducting a more thorough temperature study within the basin using continuous data to more accurately assess temperature patterns in the Green River and selected streams and tributaries (Taylor Associates and King County 2004). These continuous data will also allow more accurate comparisons with the 7-DADMax temperature criteria relative to those based on discrete grab samples, and will focus on the period of greatest concern (i.e., summer).

Summary statistics for temperature during base and storm flow are presented in Figure 9 (and Table B1, Appendix B). All sites exhibited water temperatures that were reasonably moderate and met applicable state water quality criteria on most occasions. However, it is important to emphasize that this finding is based on discrete sampling that occurred on only one occasion during the summer. Exceptions included one sample each from the Upper Green River (E319), Lower Green River (A310), and Black River (C317) that exceeded the temperature standard on August 26, 2003. In the previous year (2001-2002) of monitoring, only one sample from the Black River (C317) exceeded the standard. In 2003, base flow water temperatures ranged from 2.6°C in Soosette Creek (Y320) to 18.5°C in the Lower Green River (A310), and storm flow water temperatures ranged from 4.3°C in the Upper Green River (E319) to 13.8°C in Springbrook Creek (A317).

Sampling data indicate that water temperatures at both Green River sampling sites (E319 and A310) are generally cool. The maximum temperature measured at the Lower Green River (A310) was 18.5°C, compared to 17.3°C at the Upper Green River (E319). Spatial pattern analysis results for the Green River indicate that water temperature does not vary significantly between the upper (E319) and lower (A310) sites during base flow or storm flow (see Table P1, Appendix P). The median base flow temperature was 8.0ºC at the upper site and 8.8°C at the lower site, and the median storm flow temperature was 6.9°C at the upper site and 6.7°C at the lower site.

Spatial pattern analysis results show there are no significant differences in temperature during either base flow or storm flow for the five major stream sites (see Tables P2 and P3, Appendix P). Median base flow temperatures ranged from 9.7°C to 14.3°C at Newaukum Creek (0322) and Black River (C317), respectively. Median storm flow temperatures ranged from 7.7°C to 9.4°C at Mill (Hill) Creek (A315) and Newaukum Creek (0322), respectively. The maximum base flow water temperature (17.7°C) was measured at the Black River station (C317).

Among the tributaries, water temperatures were moderately cool during most sampling events. The highest maximum base flow temperature (15.6°C) was recorded in Panther Creek (A326), and the highest maximum storm flow temperature (12.1ºC) was recorded in the Green tributary at Lea Hill (A330). The Newaukum tributary at 236th SE (D322) had the highest median base flow temperature (13.1°C) and Crisp Creek (F321) had the highest median storm flow temperature (8.9°C).

5.3.1.2 Dissolved Oxygen

Dissolved oxygen is one of the most important water quality parameters for salmonids and other aquatic life. King County (2000) identified low dissolved oxygen concentrations as a probable cause for the decline of salmonids in all four of the major streams (Springbrook, Mill, Soos, and Newaukum Creeks) draining to the Green River. Washington State surface water standards (Table 14) require that dissolved oxygen concentrations exceed 9.5 mg/L in freshwaters designated for core salmonid rearing and 8.0 mg/L in freshwaters designated for noncore salmonid rearing (WAC 173-201A). Dissolved oxygen is a 303(d) listed parameter for each of

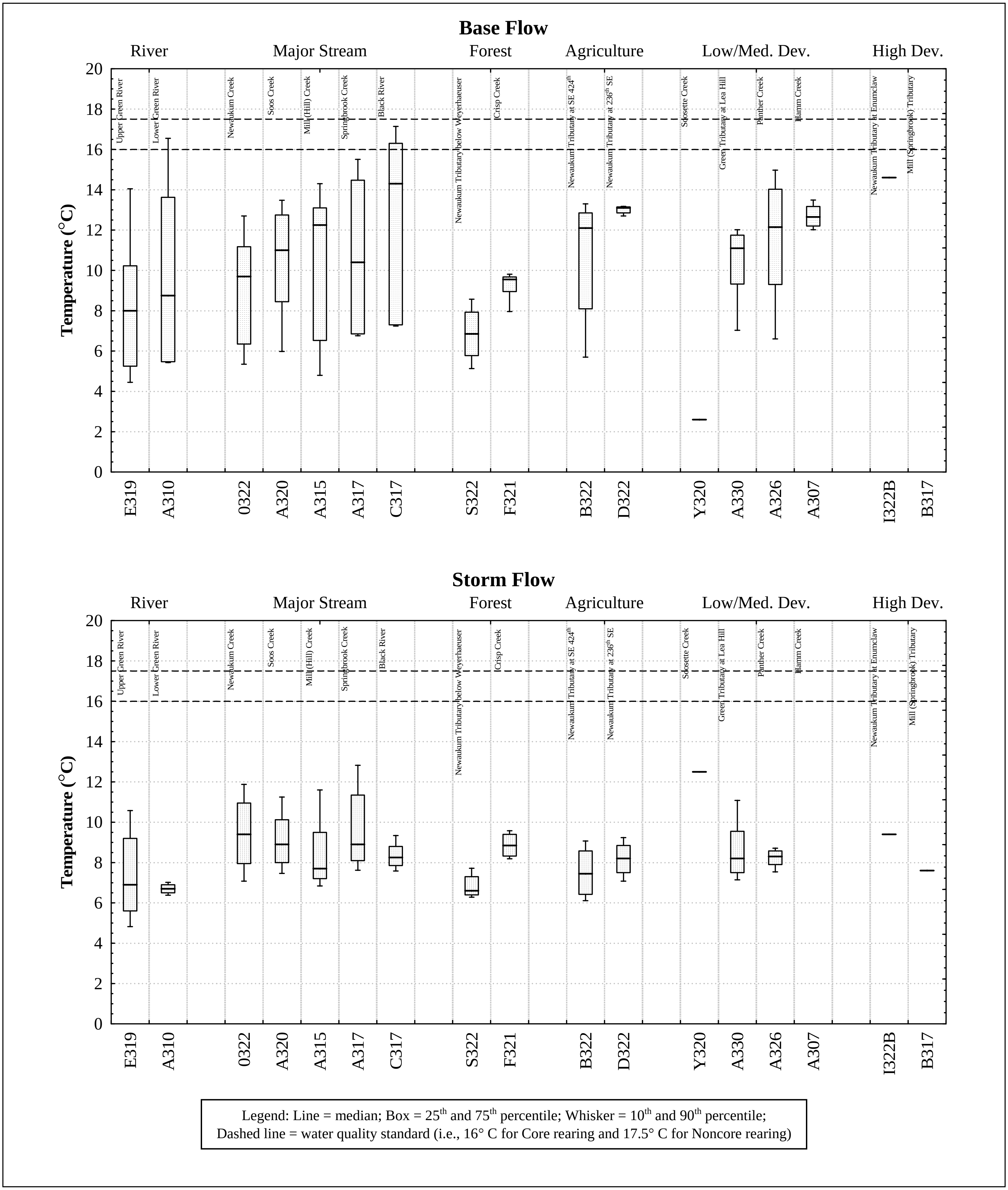


Figure 9. Temperature levels at sites in the Green-Duwamish watershed in 2003.

the five major streams, but not for the Upper Green River site (E319) or the Lower Green River site (A310).

Summary statistics for dissolved oxygen concentrations during base and storm flow are presented in Figure 10 (and Table B2, Appendix B). Among all sites, dissolved oxygen concentrations ranged from 3.2 to 13.4 mg/L during base flow and from 3.8 to 13.9 mg/L during storm flow. Spatial pattern analysis results indicate that dissolved oxygen does not vary significantly between the upper (E319) and lower (A310) sites during base flow or storm flow (see Table P1, Appendix P). Data collected in 2001-2002 showed a significant decreasing pattern downstream during both base flow and storm flow (Herrera 2004). During 2003, one of the base flow samples from each river site (Lower Green River and Upper Green River) exhibited a dissolved oxygen concentration (9.4 and 8.0 mg/L, respectively) on August 26, that did not meet the state water quality criterion (see Table 14). In addition, one storm flow sample (7.4 mg/L on November 18, 2003) from the Upper Green River (E319) also did not meet the state water quality criterion.

At the five major stream sites, median dissolved oxygen concentrations during base flow ranged from 4.9 mg/L in Springbrook Creek (A317) to 12.3 mg/L in Newaukum tributary below Weyerhaeuser (S322). During storm flow, median concentrations ranged from 7.8 mg/L in Mill (Hill) Creek (A315) to 12.1 mg/L in Soos Creek (A320). Based on the spatial pattern analysis results for these sites (Table P2, Appendix P), base flow dissolved oxygen concentrations were significantly lower ($p < 0.0001$) in Springbrook Creek (A317) and the Black River (C317) relative to those in Newaukum Creek (0322) and Soos Creek (A320). This is similar to observations made in 2001-2003 for these streams (Herrera 2004). There were no significant differences among median dissolved oxygen concentrations for these stations measured during storm flow.

Among the five major stream sites, failure to meet the dissolved oxygen criterion (Table 14) occurred most frequently (100 percent and 33 percent of base flow and storm flow samples, respectively) in Springbrook Creek (A317). Concentrations measured in the Black River (C317) did not meet the state water quality standard for 80 percent of the base flow samples. In Mill Creek (A315), the standard was not met in 33 percent of the base flow samples and 60 percent of the storm flow samples. One storm flow sample failed to meet the standard at Newaukum Creek (0322). The standard was always met at Soos Creek (A320), although few samples were collected during summer base flow when the lowest dissolved oxygen concentrations would be expected.

Among the 10 tributary sites, median dissolved oxygen concentrations were lowest during both base flow and storm flow at the Newaukum tributary at SE 424th (5.1 mg/L and 3.8 mg/L, respectively, at site B322 draining agriculture land). Tributary sites not meeting the dissolved oxygen standard include the Newaukum tributary at SE 424th (100 percent failure to meet the standard during base flow and 75 percent failure during storm flow at site B322) and the Newaukum tributary at 236th SE (33 percent not meeting standards during base flow and storm flow at site D322). Tributaries not meeting the dissolved oxygen standard in 2001-2002 but meeting the criterion on all other occasions in 2003 include Mill (Springbrook) tributary (B317,

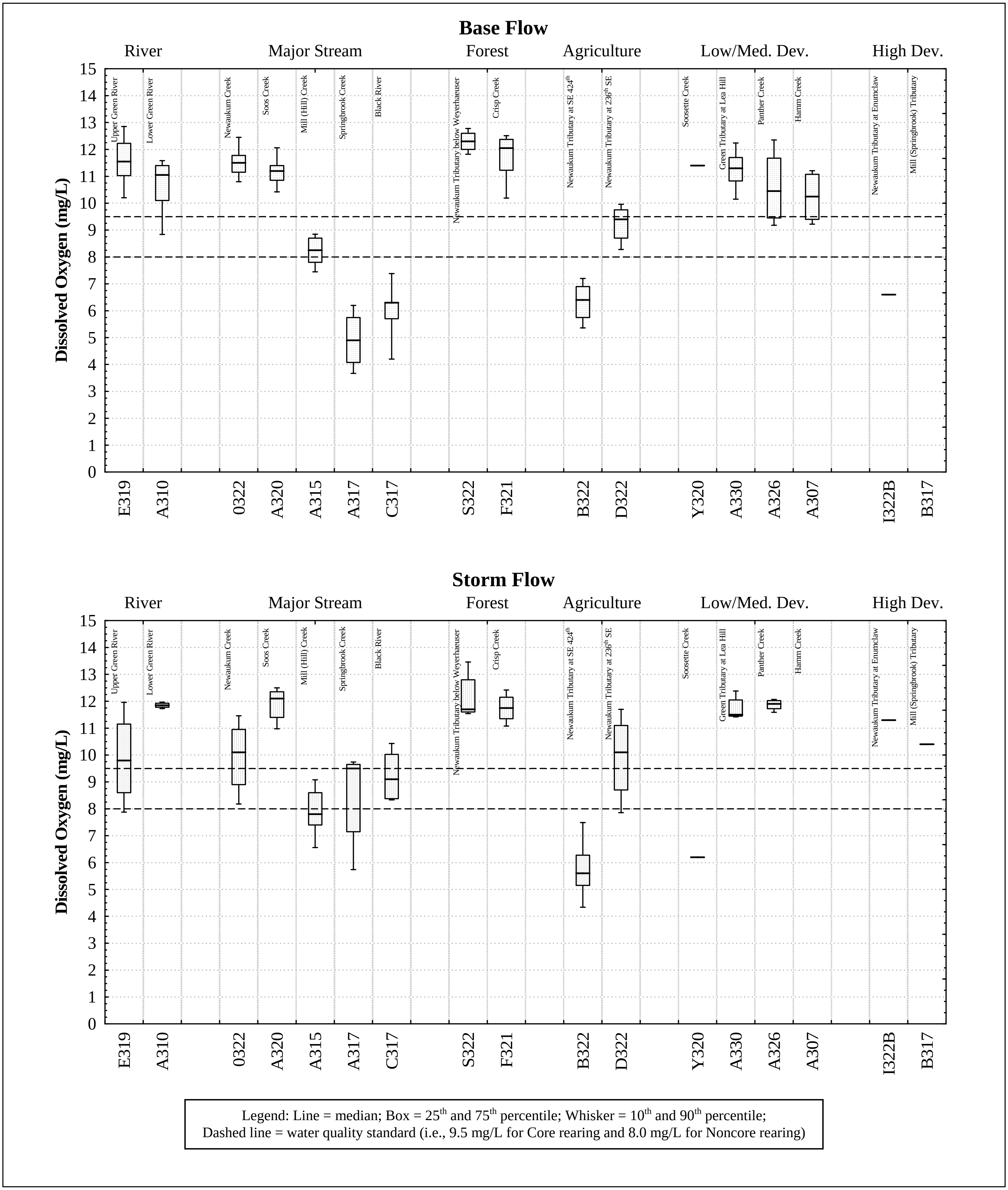


Figure 10. Dissolved oxygen concentrations at sites in the Green-Duwamish watershed in 2003.

one measurement), Soosette Creek (Y320, two measurements), and the Newaukum tributary at Enumclaw (I322B, two measurements).

5.3.1.3 pH

The hydrogen ion activity in water is measured by pH, which can have a direct effect on aquatic organisms, or an indirect effect by virtue of the fact that the toxicity of various common pollutants is markedly affected by changes in pH. Waters that exhibit a pH in the range of 0.0 to 7.0 are considered acidic, while waters with pH ranging from 7.0 to 14.0 are considered alkaline. Waters measuring 7.0 are considered neutral. State surface water quality criteria for core and noncore salmonid rearing (Table 14) require pH to be within the range of 6.5 to 8.5 (WAC 173-201A). No waterbodies included in this monitoring study are included on Ecology's 1998 303(d) water quality limited list as impaired for pH. King County (2000) identified pH as not a likely factor for the decline of salmonids in Crisp Creek, Newaukum Creek, Soos Creek, Soosette Creek, Mill (Hill) Creek, Springbrook Creek, and the Lower and Middle Green River.

Summary statistics for pH during base and storm flow are presented in Figure 11 (and Table B3, Appendix B). Base flow pH ranged from 6.5 to 8.3, and storm flow pH ranged from 6.5 to 8.0. Therefore, the pH criterion was met on all occasions at all sites. Spatial pattern analysis results for the Green River showed no difference between upstream and downstream stations in 2003, whereas a significant decreasing pattern in pH downstream was observed during base flow in 2001-2002.

The major stream sites exhibited a wide range of median pH values during base flow and storm flow. The base flow median pH ranged from 6.9 in the Black River (C317) to 7.7 in Newaukum Creek (0322), and the storm flow median ranged from 6.9 in Mill (Hill) Creek (A315) to 7.5 at Newaukum Creek (0322). Spatial pattern analysis results for the major streams showed that pH was significantly lower ($p = 0.0011$) in Springbrook Creek (A317) and the Black River (C317) relative to Newaukum Creek (0322) during base flow (Table P2, Appendix P). Further, spatial pattern analysis results for storm flow indicate that pH was significantly lower ($p = 0.0188$) in Mill (Hill) Creek (A315) relative to Newaukum Creek (0322) and Soos Creek (A320) (Table P3, Appendix P).

Among the tributary sites, the base flow median pH ranged from 6.6 in the Newaukum tributary at SE 424th (B322) to 8.0 in the Green tributary at Lea Hill (A330), and storm flow median pH ranged from 6.8 in the Newaukum tributary at SE 424th (B322) to 7.8 in Crisp Creek (F321).

5.3.1.4 Specific Conductance

Specific conductance is a measure of the ability of water to conduct an electrical current, which is directly related to the content of dissolved ions (solids) in the water. While there is no state surface water quality standard established for specific conductance, this measurement is useful for identifying sources of dissolved pollutants and for determining relative contributions of ground water, because specific conductance is typically higher in ground water than in surface water.

Summary statistics for specific conductance during base and storm flow are presented in Figure 12 (and Table B4, Appendix B). Among all samples, specific conductance ranged from 38.0 to

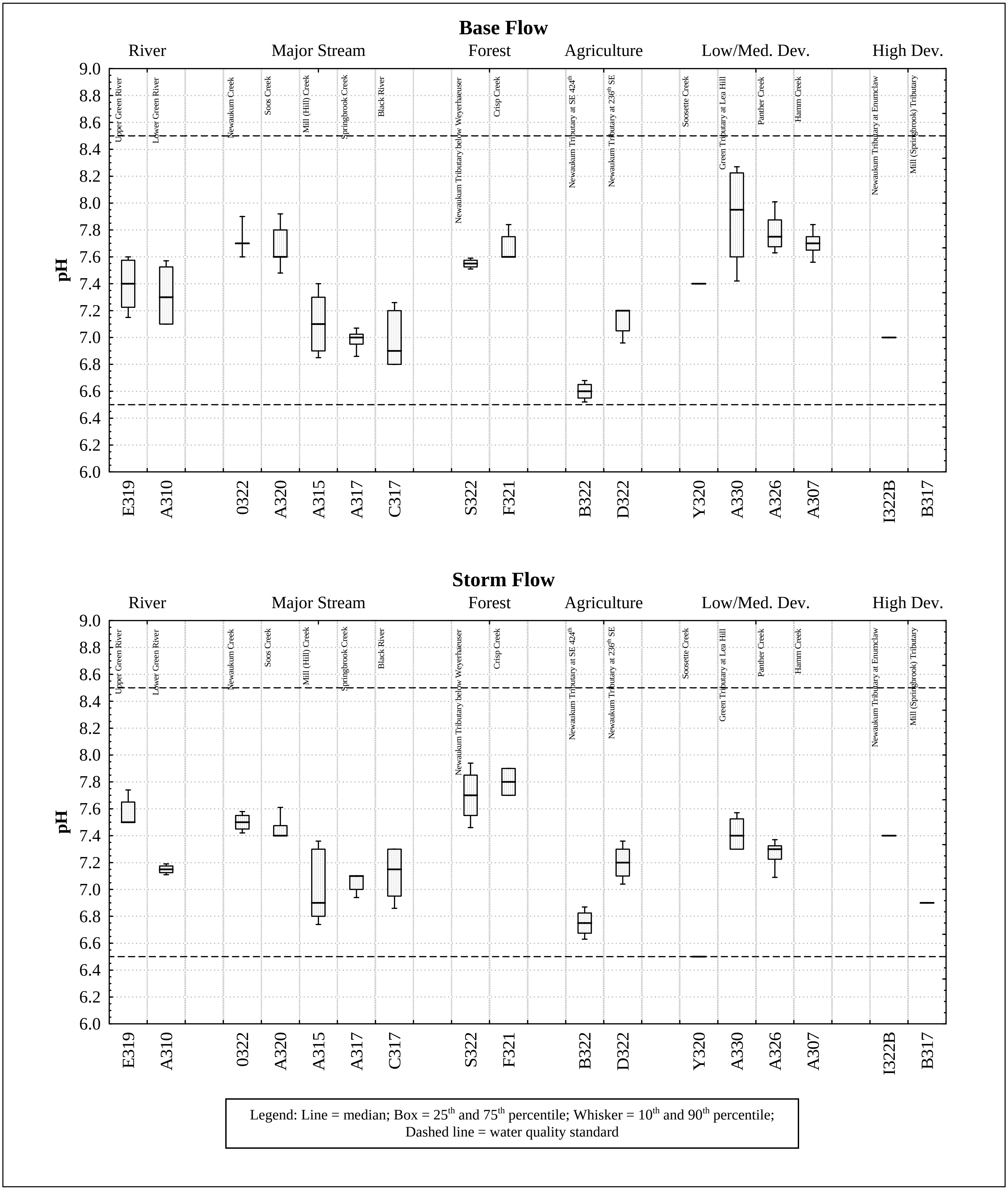


Figure 11. Levels of pH at sites in the Green-Duwamish watershed in 2003.

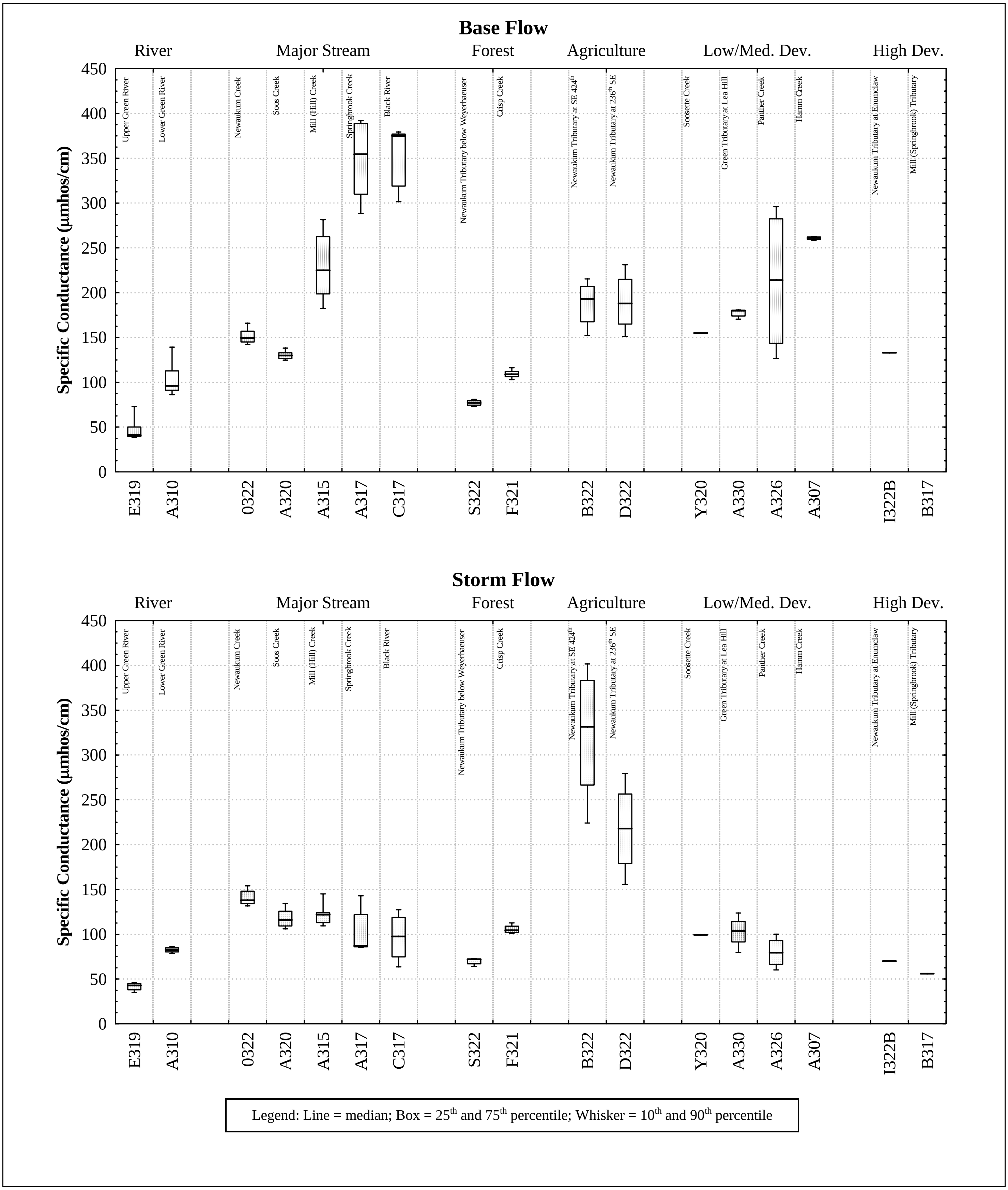


Figure 12. Specific conductance at sites in the Green-Duwamish watershed in 2003.

394 µmhos/cm during base flow and from 33.0 to 414 µmhos/cm during storm flow. Median specific conductance was higher during base flow than storm flow, with the exception of the Upper Green River (E319) and the Newaukum tributaries at SE 424th and 236th SE (B322 and D322, respectively). The median value for all the sites combined was higher during base flow (155 µmhos/cm) than during storm flow (107 µmhos/cm). The higher base flow specific conductance likely indicates ground water is a major component of the flow at these sites. During storms, specific conductance decreases because the ground water component of this flow is diluted by surface runoff.

Results of spatial pattern analysis for the Green River (Table P1, Appendix P) showed a significant increasing pattern in specific conductance from the Upper Green (E319) to the Lower Green (A310) during base flow ($p < 0.0190$). Median specific conductance levels at the upper and lower sites were 41.0 and 96.0 µmhos/cm, respectively, during base flow. During storm flow, median specific conductance levels at the upper and lower sites were 43.0 and 82.5 µmhos/cm, respectively, but these values are not significantly different due to the low number of samples (i.e., three samples for site E319 and two samples for site A310). The Upper Green River site (E319) exhibited the lowest median specific conductance of all sampling sites during base flow and storm flow, a pattern that was also observed in 2001-2002.

Based on results of the spatial pattern analysis for the five major stream sites (Table P2, Appendix P), base flow specific conductance levels were significantly lower ($p <0.0001$) in Soos Creek (A320) relative to Springbrook Creek (A317) and the Black River (C317). Median base flow specific conductance levels ranged from 130 µmhos/cm in Soos Creek (A320) to 375 µmhos/cm in the Black River (C317). Springbrook Creek (A317) had the highest maximum base flow specific conductance (394 µmhos/cm). There were no significant differences in specific conductance among the major streams during storm flow (Table P3, Appendix P). Median storm flow specific conductance levels ranged from 87.0 µmhos/cm in Springbrook Creek (A317) to 138 µmhos/cm in Newaukum Creek (0322).

Among the tributary sites, Hamm Creek (A307) exhibited the highest median specific conductance during base flow (261 µmhos/cm) while the Newaukum tributary at SE 424th (B322) exhibited the highest median specific conductance during storm flow (332 µmhos/cm). The Newaukum tributary below Weyerhaeuser (S322) had the lowest median specific conductance (77.0 µmhos/cm) during base flow and storm flow (72.0 µmhos/cm).

5.3.2 Conventionals

This section summarizes conventional parameter data collected in 2003 for the GDWQA. Summary statistics for these parameters are presented in Appendix C and results from the associated statistical spatial pattern analyses are presented in Appendix P. Conventional parameters include:

- Alkalinity
- Turbidity
- Total suspended solids

- Dissolved organic carbon
- Total organic carbon
- Biochemical oxygen demand
- Hardness.

5.3.2.1 Alkalinity

Alkalinity is a measure of the buffering capacity of water. Total alkalinity is defined as the amount of acid required to lower the pH of a water sample to the point where all of the bicarbonate [HCO_3^-] and carbonate [CO_3^{--}] have been converted to carbonic acid [H_2CO_3]. Washington State does not have surface water quality criteria for alkalinity.

Summary statistics for alkalinity during base and storm flow are presented in Figure 13 (and Table C1, Appendix C). Base flow alkalinity ranged from 14.3 to 157 mg/L (expressed as mg/L of $CaCO_3$), and storm flow alkalinity ranged from 12.3 to 69.0 mg/L (which compares to a maximum value observed of 117 mg/L in 2001-2002). Similar to conductivity, the median alkalinity of all the sites combined was higher during base flow (49.8 mg/L) than during storm flow (28.3 mg/L), and was likely caused by the increase in surface water runoff to the streams during storm events (which was also noted for the 2001-2002 data).

Between the two Green River sites (A310 and E319), alkalinity exhibited a significant increasing pattern downstream during base flow ($p = 0.0040$). However, there was no significant difference between upstream and downstream sites during storm flow sampling (see Table P4, Appendix P). A significant increasing pattern downstream was observed during both base and storm flow in 2001-2002 (Herrera 2004). Median alkalinity concentrations were 16.8 and 35.1 mg/L at upper and lower sites, respectively, during base flow. Similarly, median concentrations at the upper and lower sites were 16.2 and 27.1 mg/L, respectively, during storm flow. The Upper Green River site (E319) had the lowest base flow (16.8 mg/L) and storm flow (16.2 mg/L) median alkalinity values of all the sites.

For the five major stream sites, results from the spatial pattern analysis (Table P5, Appendix P) showed that base flow alkalinity concentrations were significantly lower ($p = 0.0250$) in Newaukum Creek (0322) relative to Black River (C317). Median base flow alkalinity among the five sites ranged from 47.9 mg/L in both Soos Creek (A320) and Newaukum Creek (0322), to 134 mg/L in the Black River (C317). As in 2001-2002, Springbrook Creek (A317) had the greatest base flow alkalinity (157 mg/L) of all the sites. Spatial pattern analysis results for storm flow showed that there were no significant differences in median alkalinity concentrations among the major stream stations (Table P6, Appendix P). The storm flow median alkalinity ranged from 26.3 mg/L in the Black River (C317) to 39.7 mg/L in Soos Creek (A320).

Among the tributary sites, median base flow alkalinity ranged from 31.0 mg/L in Newaukum tributary at Enumclaw (I322B) to 83.3 mg/L in Mill (Springbrook) tributary (B317). Median storm flow alkalinity ranged from 18.9 mg/L at Newaukum tributary at Enumclaw (I322B) to 66.8 mg/L at Newaukum tributary at SE 424th (B322), which also exhibited the maximum storm

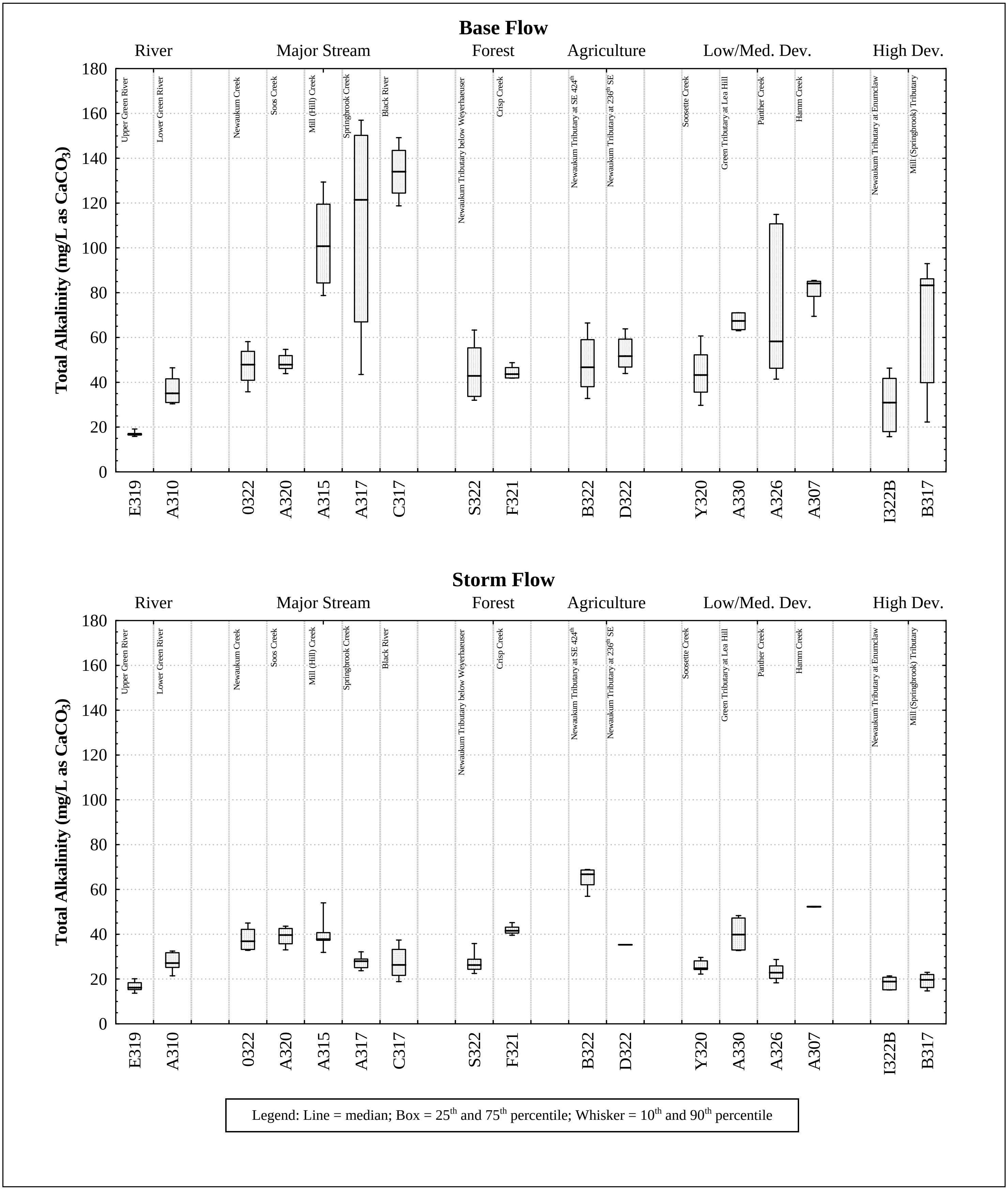


Figure 13. Alkalinity concentrations at sites in the Green-Duwamish watershed in 2003.

flow alkalinity (69.0 mg/L) of all the sampling sites. Similar patterns among the tributary sites were observed in 2001-2002 (Herrera 2004).

5.3.2.2 Turbidity

Turbidity is a measure of water clarity that is determined by how the transmission of light is scattered as it passes through water. The increase in the amount of particulate matter in water reduces clarity (or transparency) by increasing the scattering of light. Measurements of turbidity are expressed in nephelometric turbidity units (NTU). Washington State has surface water quality criteria for turbidity (WAC 173-201A) that restrict turbidity increases from human sources to a maximum of 5 NTU over background when the background is 50 NTU or less. When background turbidity is over 50 NTU, turbidity resulting from human sources cannot increase background levels by more than 10 percent. Because background data are not available for the grab samples collected during base flow and storm flow, direct comparisons with the turbidity criteria are not possible and were not made as part of this analysis. No waterbodies in this monitoring study are identified as on the Ecology 1998 303(d) list as water quality limited for turbidity.

Summary statistics for turbidity during base and storm flow are presented in Figure 14 (and Table C2, Appendix C). Base flow turbidity ranged from 0.5 to 34.8 NTU, and storm flow turbidity ranged from 0.6 to 380 NTU. The median turbidity of all the sites combined was higher during storm flow (9.9 NTU) than base flow sampling (3.1 NTU). This increase in turbidity was likely caused by the increase in surface runoff to the streams (and the associated mobilization of suspended solids from erosion or washoff from urban surfaces) during storms.

Spatial pattern analysis results for the Green River (Table P4, Appendix P) indicate that there was a significant ($p = 0.0485$) increase in median turbidity downstream during base flow, but there was no significant difference between the upper (E319) and lower (A310) sites during storm flow. Base flow turbidity levels were generally low with median values of 1.8 NTU at the Upper Green (E319) and 3.0 NTU at the Lower Green (A310). Storm flow turbidity levels were slightly higher, with median values of 4.7 NTU at the Upper Green (E319) and 9.6 NTU at the Lower Green (A310).

Based on spatial pattern analyses for the major stream sites (Table P5, Appendix P), base flow turbidity levels were significantly higher ($p = 0.0010$) in Springbrook Creek (A317) relative to Soos Creek (A320). Median base flow turbidity levels ranged from 1.5 NTU in Soos Creek (A320) to 19.7 NTU in Springbrook Creek (A317). The spatial pattern analysis for storm flow (Table P6, Appendix P) showed no significant difference in median turbidity among major stream stations. Median storm flow turbidity ranged from 4.9 NTU in Soos Creek (A320) to 17.2 NTU in Springbrook Creek (A317).

Median base flow turbidity values in the tributaries ranged from 0.5 NTU in Crisp Creek (F321) to 16.7 NTU in the Mill (Springbrook) tributary (B317). Median values during storm flow ranged from 2.0 NTU at Crisp Creek (F321) to 28.0 NTU at the Green tributary at Lea Hill (A330). Panther Creek (A326) exhibited the maximum turbidity value (380 NTU) of all the sites

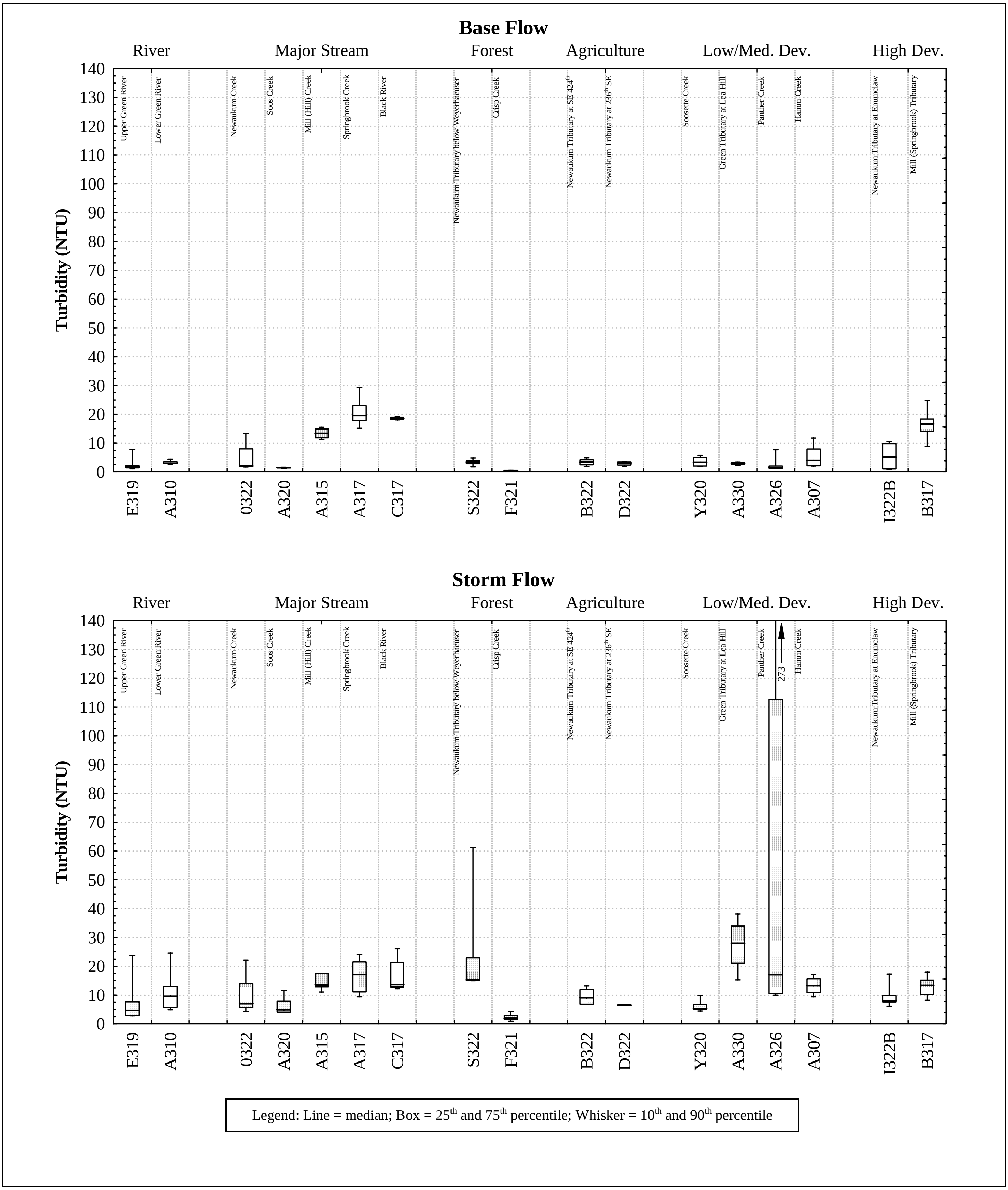


Figure 14. Turbidity levels at sites in the Green-Duwamish watershed in 2003.

during storm flow sampling. Tributary sites exhibiting elevated turbidity (i.e., greater than 30 NTU) during storm flow include the Newaukum tributary below Weyerhaeuser (S322), the Green tributary at Lea Hill (A330), and Panther Creek (A326).

5.3.2.3 Total Suspended Solids

Total suspended solids (TSS) is a measurement of the solid materials in water that are retained on a standard glass-fiber filter. Suspended solids, especially the finer fractions, reduce light penetration in water and can have a smothering effect on fish redds and benthic biota. Suspended solids are also closely associated with other pollutants such as nutrients, bacteria, metals, and organic compounds. These pollutants tend to adsorb onto solids particles and are consequently transported in surface runoff to receiving waters if no onsite controls are implemented for solids removal. No state surface water quality criteria have been established for total suspended solids.

According to King County (2000), total suspended solids are not likely a concern for salmonids in Crisp Creek, Soos Creek, Newaukum Creek, or the Lower and Middle Green River. However, more data are needed to verify this conclusion. Elevated total suspended solids concentrations that could potentially be a problem for salmonids have been found in Mill (Hill) Creek and Springbrook Creek. However, more data on concentrations and duration are needed to determine the potential effects on salmonids in these streams (Kerwin and Nelson 2000).

Summary statistics for total suspended solids during base and storm flow are presented in Figure 15 (and Table C3, Appendix C). Base flow TSS concentrations ranged from 0.6 mg/L to 71.6 mg/L, and storm flow TSS concentrations ranged from 1.5 to 698 mg/L. As with turbidity, the median total suspended solids concentration for all sites combined was higher during storm flow (12.4 mg/L) than base flow (4.8 mg/L), and was likely caused by the increase in surface runoff to these streams during storm events.

Spatial pattern analysis for the Green River sites (Table P4, Appendix P) show that total suspended solids concentrations increase significantly ($p = 0.0485$) between the upper (E319) and lower (A310) sites during base flow. During base flow, median total suspended solids concentrations were 2.3 and 10.4 mg/L at the upper and lower sites, respectively. There were no significant differences between these two sites during storm flow.

Results of spatial pattern analysis for the major stream sites show that there were no significant differences among these sites during base flow or storm flow (Tables P5 and P6, Appendix P). Median base flow TSS concentrations ranged from 3.4 mg/L at Soos Creek (A320) to 10.1 mg/L at Black River (C317). Median storm flow TSS concentrations ranged from 8.2 mg/L at Soos Creek (A320) to 23.0 mg/L at Springbrook Creek (A317).

Among the tributaries, median TSS concentrations during base flow ranged from 0.9 mg/L in Crisp Creek (F321) to 12.4 mg/L in the Mill (Springbrook) tributary (B317). Also, Crisp Creek (F321) had the lowest median concentration (3.0 mg/L) of all the sampling sites during storm flow. The Green tributary at Lea Hill (A330) had the highest median TSS value (45.0 mg/L)

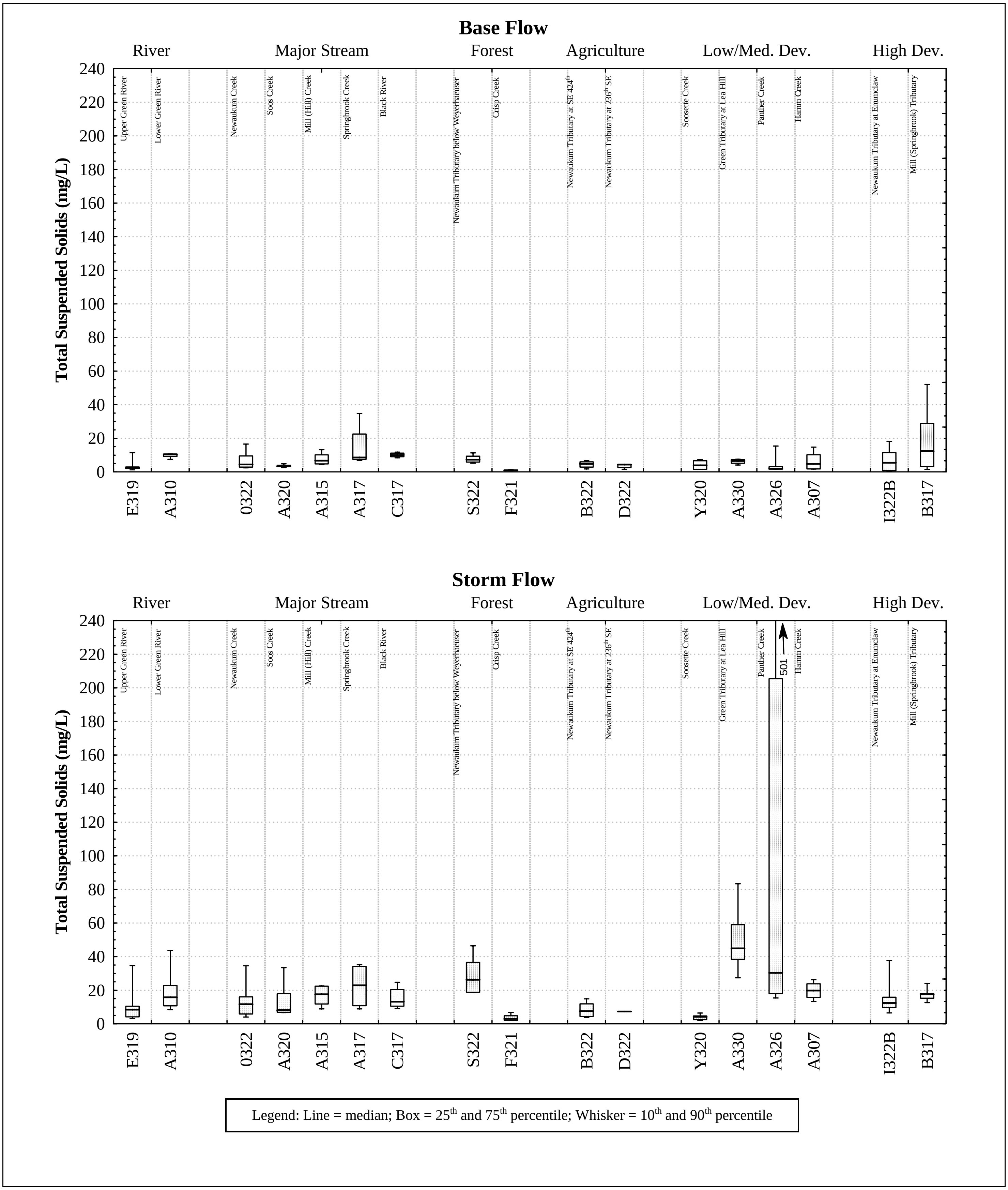


Figure 15. Total suspended solids concentrations at sites in the Green-Duwamish watershed in 2003.

during storm flow. Tributary sites that also had high median TSS concentrations (i.e., greater than 10 mg/L) during storm flow include the Newaukum tributary below Weyerhaeuser (S322), Panther Creek (A326), Hamm Creek (A307), the Newaukum tributary at Enumclaw (I322B), and the Mill (Springbrook) tributary (B317). Panther Creek (A326) had the maximum storm flow TSS concentration (698 mg/L) among all sites.

5.3.2.4 Dissolved Organic Carbon

Dissolved organic carbon (DOC) is a measure of the amount of dissolved organic matter in water. Surface water sources of dissolved organic carbon include precipitation, leaching, and organic decomposition. Dissolved organic carbon affects the attenuation of visible and ultraviolet light penetration within water and is also a key driver in stream metabolism (Larson et al. 2003). Furthermore, DOC can reduce the acute toxicity of many metals through ligand complexation with free metal ions (Bergman and Doward-King 1997). Washington State does not have surface water quality criteria for dissolved organic carbon.

Summary statistics for dissolved organic carbon during base and storm flow are presented in Figure 16 (and Table C4, Appendix C). Base flow DOC concentrations ranged from 1.4 to 29.5 mg/L, and storm flow DOC concentrations similarly ranged from 1.8 to 24.9 mg/L. There were no significant differences in dissolved organic carbon concentrations between the two Green River sites (A310 and E319) during base flow or storm flow (see Table P4, Appendix P). In 2001-2002, dissolved organic carbon concentrations showed a significant increasing pattern downstream during base flow and storm flow.

Results from the spatial pattern analysis for the major stream sites (Table P5, Appendix P) show that base flow DOC concentrations were significantly higher ($p = 0.0182$) in Mill Creek (A315) relative to Soos Creek (A320). Median DOC concentrations during base flow ranged from 3.2 mg/L at Soos Creek (A320) to 10.3 mg/L at Mill Creek (A315). Storm flow DOC concentrations were significantly higher ($p = 0.0183$) in Newaukum Creek (0322) than Springbrook Creek (A317) (Table P6, Appendix P). Median storm flow DOC concentrations ranged from 6.2 mg/L at Springbrook Creek (A317) to 10.4 mg/L at Newaukum Creek (0322). Significant differences in DOC concentrations were observed among the major stream sites in 2001-2002 during base flow but not during storm flow (Herrera 2004).

Among the tributary sites, median base flow DOC concentrations ranged from 2.6 mg/L at three sites (Crisp Creek [F321], the Newaukum tributary below Weyerhaeuser [S322], and the Green tributary at Lea Hill [A330]) to 15.1 mg/L in the Newaukum tributary at SE 424th (B322). Crisp Creek (F321) had the lowest minimum base flow DOC concentration (1.6 mg/L) among all tributary sites. Median storm flow DOC concentrations ranged from 3.9 mg/L in Crisp Creek (F321) to 24.0 mg/L in Newaukum tributary at SE 424th (B322). Newaukum tributary at SE 424th (B322) also exhibited the maximum dissolved organic carbon concentration (24.9 mg/L) during storm flow among all sites.

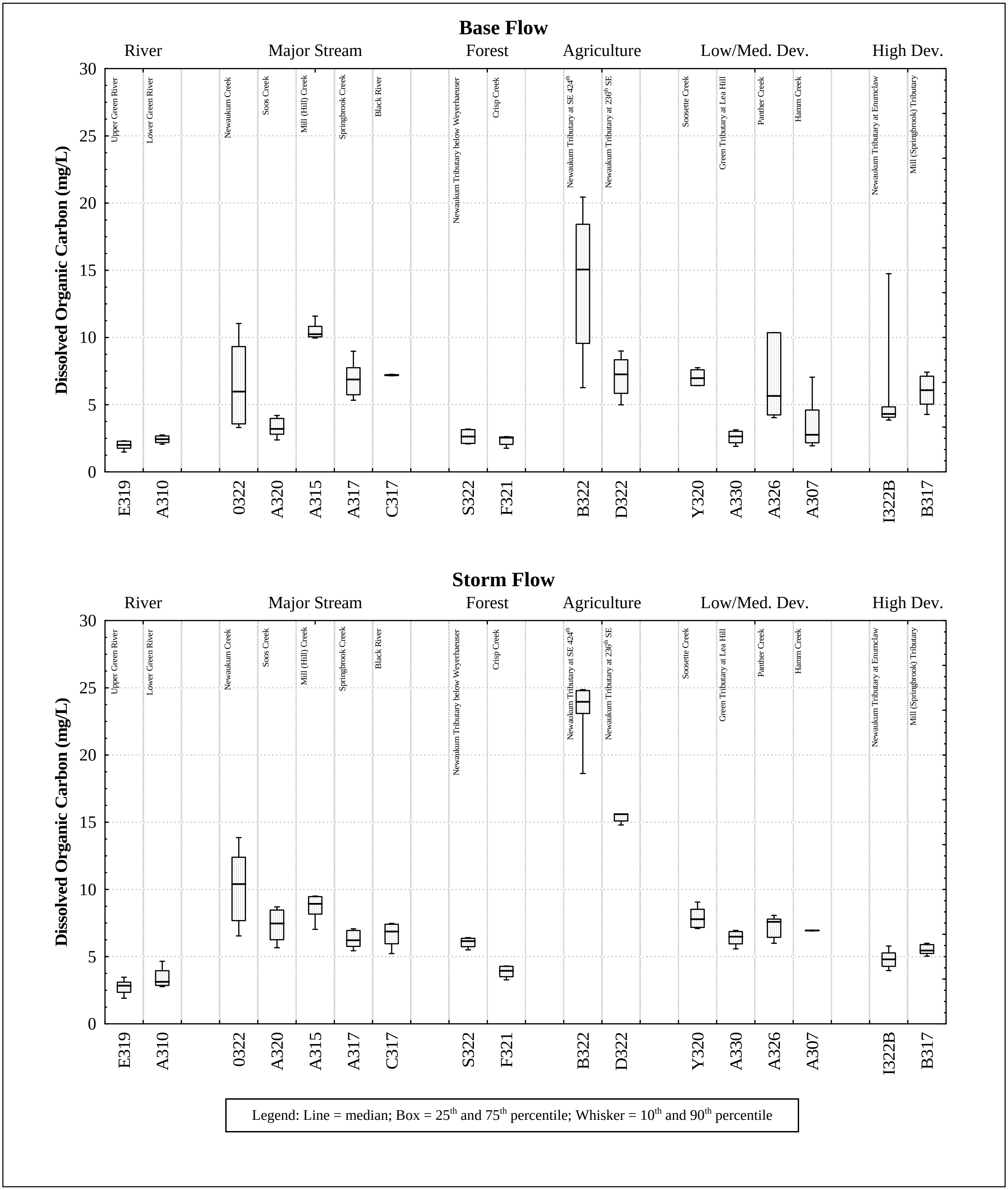


Figure 16. Dissolved organic carbon concentrations at sites in the Green-Duwamish watershed in 2003.

5.3.2.5 Total Organic Carbon

Total organic carbon (TOC) measures the total amount of organic matter (particulate and dissolved) in water, including organic carbon. TOC affects nutrient cycling, biological availability, and chemical transport and interactions. As the amount of organic matter increases in a water body, more oxygen is consumed due to the oxidation of the more labile fractions of TOC by bacteria. Therefore, higher TOC concentrations may result in lower dissolved oxygen concentrations in a water body from this oxidation. Washington State has not promulgated surface water quality criteria for total organic carbon.

Summary statistics for total organic carbon during base and storm flow are presented in Figure 17 (and Table C5, Appendix C). Among all sites, base flow TOC concentrations ranged from 1.6 to 33.8 mg/L, and storm flow TOC concentrations similarly ranged from 2.1 to 30.1 mg/L. The median TOC concentration for all sites combined was higher during storm flow (8.1 mg/L) than during base flow (4.9 mg/L). The median base flow TOC concentration ranged from 2.2 mg/L in the Upper Green River (E319) to 15.1 mg/L in the Newaukum tributary at SE 424th (B322), and the median storm flow TOC concentration ranged from 3.1 mg/L in the Upper Green River (E319) to 24.6 mg/L in the Newaukum tributary at SE 424th (B322).

Based on the results of the spatial pattern analysis for the Green River (Table P4, Appendix P), there were no significant differences in total organic carbon concentrations between the upper (E319) and lower (A310) sites during base flow sampling. During storm flow, the median TOC concentration increased significantly ($p = 0.0140$) downstream from the upper site (3.1 mg/L) to the lower site (4.6 mg/L).

Results from the spatial pattern analysis for the major stream sites (Table P5, Appendix P) show that base flow TOC concentrations were significantly higher ($p = 0.0147$) in Mill Creek (A315) and Springbrook Creek (A317) relative to Soos Creek (A320). Spatial pattern analysis results for storm flow (Table P6, Appendix P) show that total organic carbon concentrations were significantly higher ($p = 0.0156$) in Newaukum Creek (0322) relative to the Black River (C317). Median base flow TOC concentrations ranged from 3.4 mg/L at Soos Creek (A320) to 11.3 mg/L at Mill (Hill) Creek (A315). Median storm flow TOC concentrations ranged from 7.4 mg/L at Black River (C317) to 12.1 mg/L at Newaukum Creek (0322).

Among the tributary sites, median base flow TOC concentrations ranged from 2.1 mg/L in Crisp Creek (F321) and the Green tributary at Lea Hill (A330) to 15.1 mg/L in the Newaukum tributary at SE 424th (B322). Median storm flow TOC concentrations ranged from 3.9 mg/L in the Green tributary near TPU diversion (F321) to 24.6 mg/L in Newaukum tributary at SE 424th (B322). Newaukum tributary at SE 424th (B322) also exhibited the maximum storm flow TOC concentration (30.1 mg/L) of all sites.

5.3.2.6 Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is primarily a measure of the amount of oxygen required by aerobic biological processes to break down the organic matter in water. Washington State does

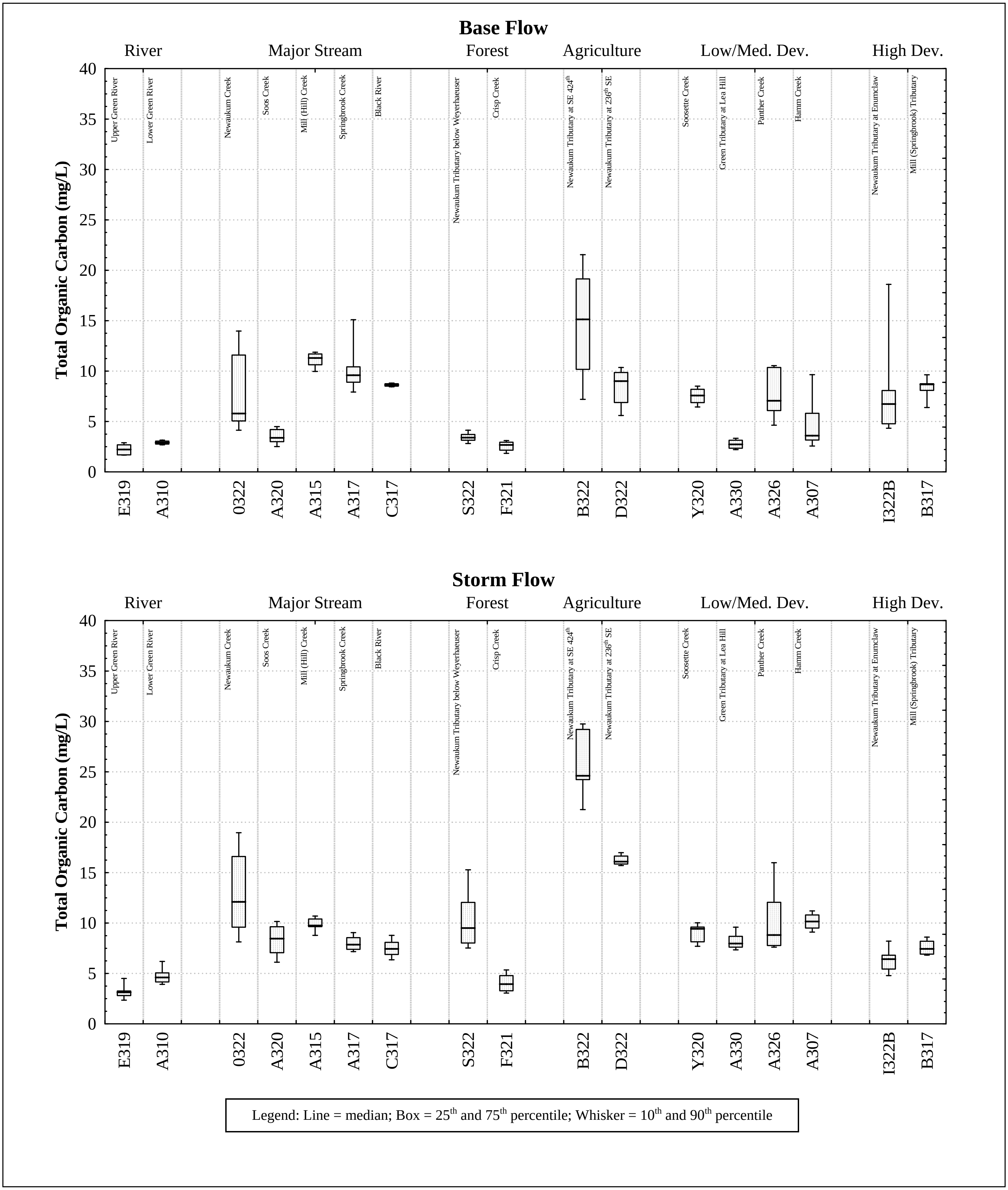


Figure 17. Total organic carbon concentrations at sites in the Green-Duwamish watershed in 2003.

not have surface water quality criteria for BOD. Very limited BOD data were collected during 2003. A total of six BOD samples (only two of which were above the detection limit of 2.0 mg/L) were collected from three different sites during base flow, and 23 BOD samples (only seven of which were above the detection limit of 2.0 mg/L) were collected from 16 different sites during storm flow. Summary statistics for these data are presented in Table C6 (Appendix C). The median base flow BOD concentration was equivalent to the detection limit (2.0 mg/L) for all base flow samples and for all storm flow samples. Out of all the collected samples, the maximum BOD concentration (12.0 mg/L) was measured during base flow in the Newaukum tributary at Enumclaw (I322B), which may be indicative of septic/sewer problems in this highly developed basin. In 2001-2002, the Newaukum tributary at SE 424th (B322) exhibited the highest maximum BOD concentration (44 mg/L), which was attributed to inputs of animal waste from agricultural/pasture land use in the basin (Herrera 2004).

5.3.2.7 Hardness

Total hardness is defined as the sum of calcium and magnesium concentrations (both expressed as calcium carbonate) in water. Hardness directly affects the toxicity of some heavy metals (i.e., some metals are more toxic at lower levels of hardness, especially divalent metals). Hardness measurements are necessary for determining compliance with state water quality criteria for dissolved cadmium, chromium, copper, lead, nickel, silver, and zinc. Washington State has not promulgated surface water quality criteria for hardness.

Waters with low hardness are referred to as "soft" and waters with a high hardness are referred to as "hard". The United State Geological Survey (USGS) uses the following numeric ranges (expressed as calcium carbonate) to classify hardness: 0 to 60 mg/L as soft, 61 to 120 mg/L as moderately hard, 121 to 180 mg/L as hard, and greater than 180 as very hard (USGS 2003).

Summary statistics for hardness during base and storm flow are presented in Figure 18 (and Table C7, Appendix C). During sampling, total hardness varied from soft to hard. Base flow hardness ranged from 13.6 to 132 mg/L, and storm flow hardness ranged from 14.7 to 109 mg/L. As with conductivity and alkalinity, the median hardness for all the sites was higher during base flow (54.3 mg/L) than storm flow (35.5 mg/L) and was likely caused by dilution of the ground water component by surface water runoff to the streams during storm events.

Waters of the Green River were soft during base and storm flow sampling. Results of the spatial patterns analysis (Table P4, Appendix P) show that the hardness in the Green River increases significantly downstream during both base flow ($p = 0.0040$) and storm flow ($p = 0.0012$). Median hardness increased downstream from 14.9 to 33.3 mg/L during base flow, and increased downstream from 15.2 to 30.0 mg/L during storm flow. The Upper Green River site (E319) had the lowest median hardness of all the sites during base flow (14.9 mg/L) and storm flow (15.2 mg/L).

Among the major streams, the median hardness ranged from 51.9 mg/L in Soos Creek (A320) to 112 mg/L in the Black River (C317) during base flow, and ranged from 30.5 mg/L in the Black River (C317) to 54.3 mg/L in Newaukum Creek (0322) during storm flow. Base flow spatial

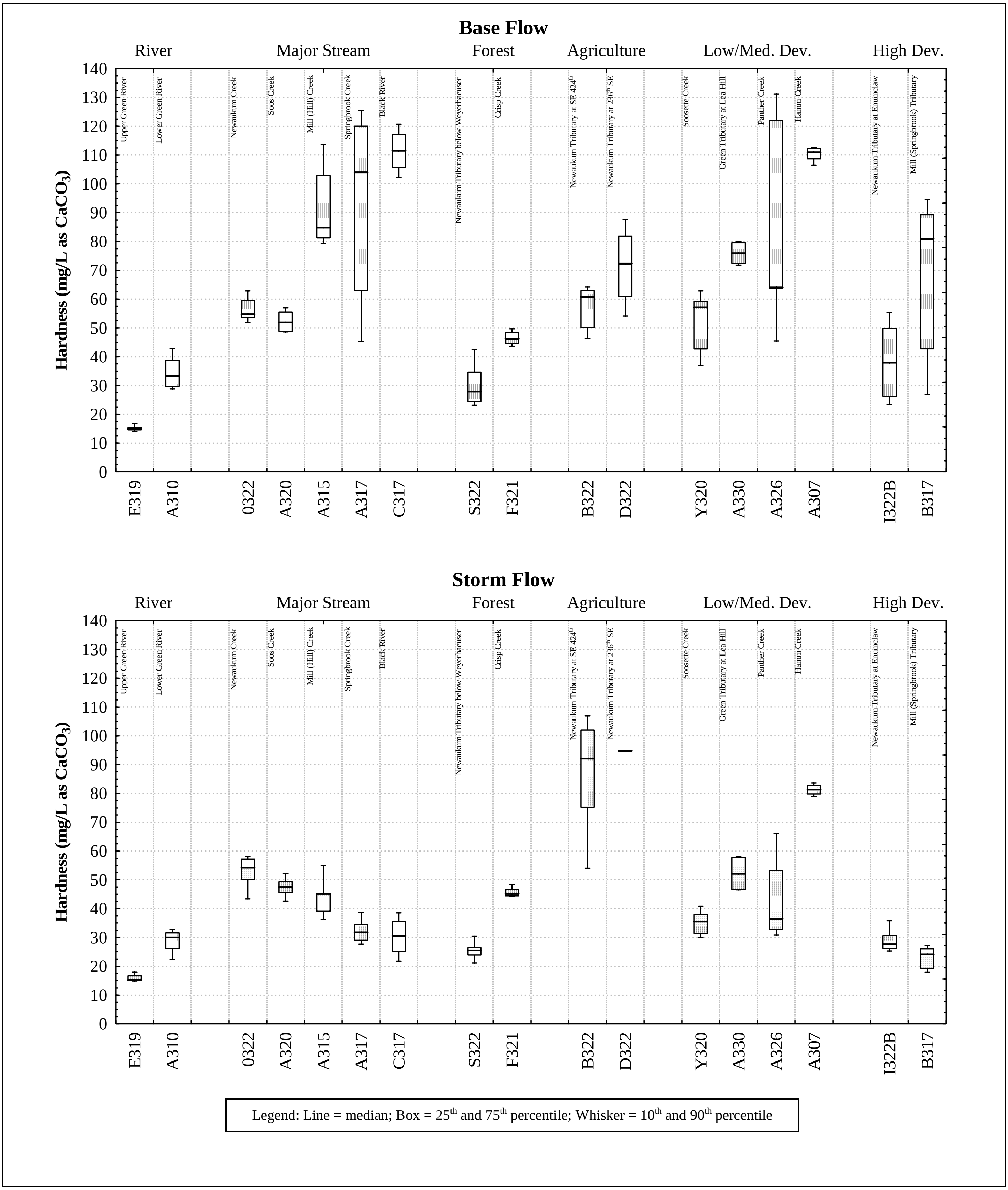


Figure 18. Hardness concentrations at sites in the Green-Duwamish watershed in 2003.

pattern analysis results (Table P5, Appendix P) show that there were no significant differences in hardness values among major streams. Results of storm flow spatial pattern analysis (Table P6, Appendix P) show that Newaukum Creek (0322) has significantly higher ($p = 0.0043$) hardness relative to the Black River (C317).

The median base flow hardness among the tributary sites ranged from 27 mg/L in the Newaukum tributary downstream of Weyerhaeuser (S322) to 111 mg/L in Hamm Creek (A307), and median storm flow hardness ranged from 24.1 mg/L in Mill (Springbrook) tributary (B317) to 92.1 mg/L in the Newaukum tributary at 236th SE (B322). The Newaukum tributary at SE 424th (B322) exhibited the highest median storm flow hardness (92.1 mg/L) and the maximum storm flow hardness (109 mg/L) of all sites.

5.3.3 Microbiology

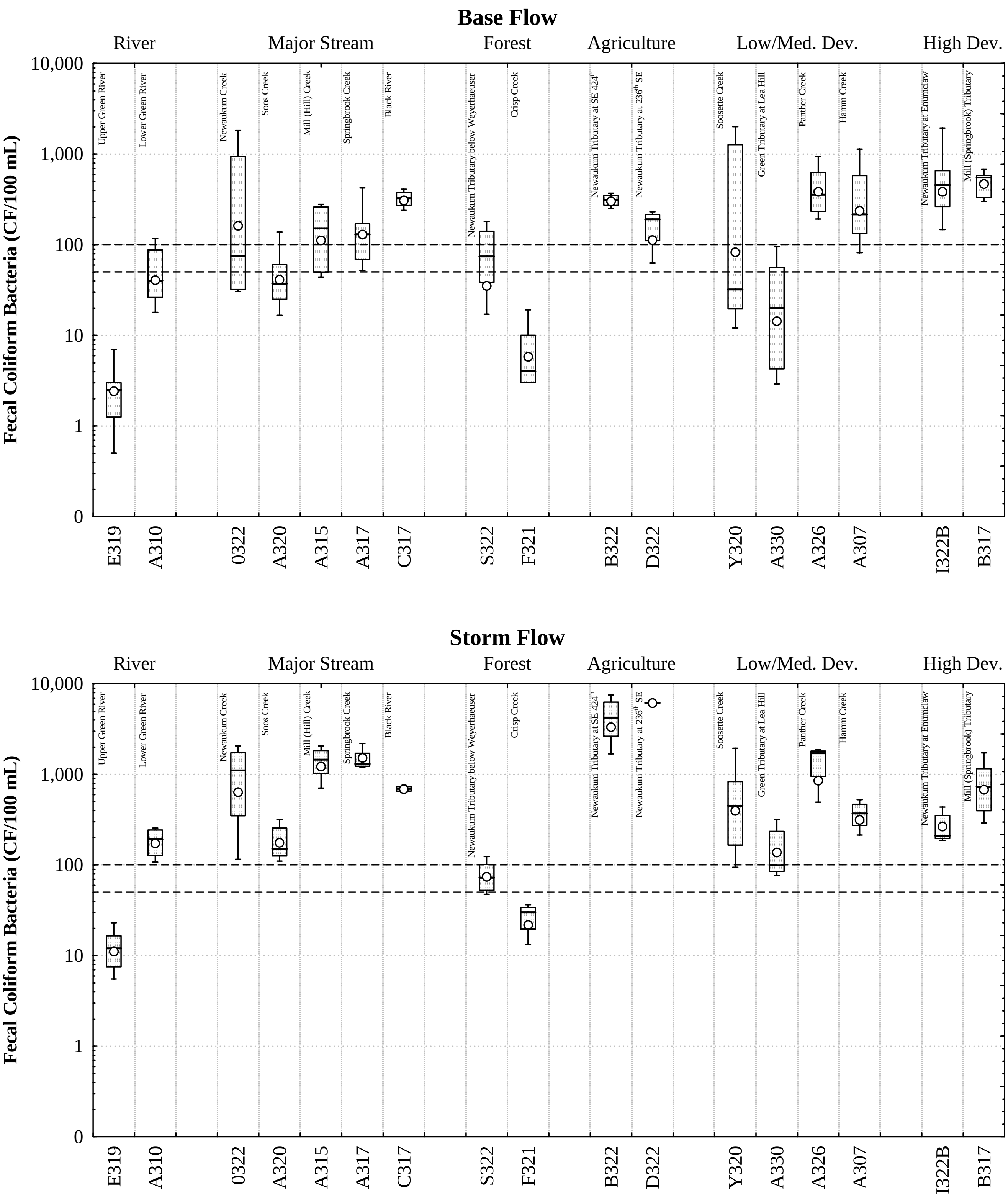
This section summarizes the microbiological data collected in 2003 for the GDWQA. Summary statistics for the following microbiological parameters are presented in Appendix D and results from associated statistical spatial pattern analyses are presented in Appendix P:

- Fecal coliform bacteria
- Enterococci bacteria
- *E. coli* bacteria.

5.3.3.1 Fecal Coliform Bacteria

Urban runoff characteristically contains elevated levels of fecal coliform bacteria. These organisms are used as indicators of fecal contamination from humans and other warm-blooded animals. Human sources include failing septic systems, municipal wastewater discharges, leaking wastewater conveyance systems or side sewers, and cross-connections with municipal wastewater systems. Animal sources include pets, livestock, and wildlife (e.g., birds and mammals). The simple presence of these bacteria does not necessarily indicate a threat to public health because only a small portion are likely to be pathogenic to humans. However, their use as an “indicator” of potential fecal contamination is considered important in the early detection of problems that could lead to a public health threat. Washington State surface water quality criteria (WAC 173-201A) for fecal coliform bacteria are presented in Table 14. The Lower and Middle Green River, Springbrook Creek, Mill Creek, Soos Creek, Soosette Creek, Newaukum Creek, and Crisp Creek are included on the Ecology 1998 303(d) water quality limited list for fecal coliform bacteria.

Summary statistics for fecal coliform bacteria during base and storm flow are presented in Figure 19 (and Table D1, Appendix D). Fecal coliform bacteria concentrations ranged from 0 to 3,200 colony forming units (CFU)/100 milliliters (mL) during base flow, and from 4 to 8,272 CFU/100 mL during storm flow. During base flow, the state criteria were exceeded at all sites except the Upper Green River (E319), Soos Creek (A320), and Crisp Creek (F321). During storm flow, the state criteria were exceeded at all sites except the Upper Green River (E319) and Crisp Creek



Legend: Line = median; Circle = geometric mean; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile;
Dashed line = water quality standard (i.e., 50 CFU/100 mL for Extraordinary Primary Contact Recreation and
100 CFU/100 mL for Primary Contact Recreation)

Figure 19. Fecal coliform bacteria concentrations at sites in the Green-Duwamish watershed in 2003.

(F321). The geometric mean for all sites was higher during storm flow (300 CFU/100 mL) than base flow (54 CFU/100 mL), indicating that storm runoff is a significant source of these bacteria.

The Upper Green River site (E319) had low fecal coliform bacteria concentrations during base flow and storm flow with no exceedances of the state criteria. In contrast, state criteria were exceeded at the lower site (A310) during base flow and storm flow. In 2001-2002, the lower site (A310) did not exceed state criteria for fecal coliform bacteria during base flow. Spatial pattern analysis results show that fecal coliform bacteria concentrations increase significantly between the upper site (E319) and lower site (A310) during base flow ($p = 0.0238$) and storm flow ($p = 0.0022$) (Table P7, Appendix P). Between the upper site (E319) and the lower site (A310), the geometric mean fecal coliform bacteria concentration increased from 0 to 41 CFU/100 mL during base flow, and from 11 to 173 CFU/100 mL during storm flow, respectively.

Spatial pattern analysis results for the five major stream sites show there were no significant differences in fecal coliform bacteria concentrations during either base flow or storm flow (Tables P8 and P9, Appendix P). Geometric mean base flow fecal coliform bacteria concentrations ranged from 41 CFU/100 mL at Soos Creek (A320) to 308 CFU/100 mL at the Black River (C317). Geometric mean storm flow fecal coliform bacteria concentrations ranged from 175 CFU/100 mL at Soos Creek (A320) to 1,514 CFU/100 mL at Black River (C317). The state fecal coliform bacteria criteria were exceeded at all major streams except Soos Creek (A320) during base flow, and at all major streams during storm flow. Similar results were observed in 2001-2002 with the exception that Newaukum Creek (0322) did not exceed the state standard during base flow.

Among the tributaries, geometric mean base flow fecal coliform bacteria concentrations ranged from 6 CFU/100 mL in Crisp Creek (F321) to 467 CFU/100 mL in Mill (Springbrook) tributary (B317). All tributary sites exceeded state criteria during base flow except Crisp Creek (F321).

The tributary storm flow geometric mean fecal coliform bacteria concentrations ranged from 22 CFU/100 mL in Crisp Creek (F321) to 3,308 CFU/100 mL in the Newaukum tributary at SE 424th (B322). All tributary sites exceeded state criteria during storm flow sampling with the exception of Crisp Creek (F321) (which previously exceeded the state criteria during storm flow in 2001-2002).

5.3.3.2 Enterococci Bacteria

The measurement of enterococci bacteria is used as an indicator to determine the risk to human health in surface waters from the presence of a select sub-group of fecal streptococcus bacteria (*Streptococcus faecalis*, *S. faecium*, *S. gallinarum*, and *S. avium*). And, as with fecal coliform bacteria, their presence is attributed to contamination from humans and other warm-blooded animals. Currently, no Washington State surface water quality criteria exist for enterococci bacteria in freshwaters. However, the EPA recommends that states use either enterococci or *E. coli* as an indicator for freshwater contamination (U.S. EPA 2002b). The EPA water quality criteria for bacteria in bathing (full body contact) recreational waters specify that the geometric mean of enterococci bacteria should not exceed 33 organisms/100 mL during steady-state conditions (U.S. EPA 1986).

Summary statistics for enterococci bacteria during base and storm flow are presented in Figure 20 (and Table D2, Appendix D). Base flow enterococci bacteria concentrations ranged from 1 to 4,800 CFU/100 mL, and storm flow concentrations ranged from 5 to 5,740 CFU/100 mL. During base flow, the EPA criterion was exceeded at all sites (having one or more samples) except the Upper Green River (E319), Lower Green River (A310), Soos Creek (A320), Newaukum tributary below Weyerhaeuser (S322), Crisp Creek (F321), Green tributary at Lea Hill (A330), and Panther Creek (A326). During storm flow, the EPA criterion was exceeded at all sites except the Upper Green River (E319) and the Newaukum tributary below Weyerhaeuser (S322). The geometric mean for all sites was much higher during storm flow (309 CFU/100 mL) than base flow (51 CFU/100 mL), indicating that storm runoff is a significant source of these bacteria.

Spatial pattern analysis was not performed for the Green River during base flow because insufficient data (i.e., only one or two values per site) were available to perform the analysis. There were no significant differences between upstream and downstream stations for the Green River during storm flow (Table P7, Appendix P). In 2001-2002, a significant increasing downstream pattern was observed during base flow and storm flow.

Among the major streams, geometric mean base flow enterococci concentrations ranged from 117 CFU/100 mL in Newaukum Creek (0322) to 257 CFU/100 mL in Springbrook Creek (A317), and geometric mean storm flow enterococci concentrations ranged from 325 CFU/100 mL in Newaukum Creek (0322) to 2,433 in Springbrook Creek (A317). Base flow and storm flow enterococci bacteria concentrations do not differ significantly among the major streams (Tables P8 and P9, Appendix P). However, storm flow enterococci concentrations were significantly higher in Springbrook Creek (A317) relative to Soos Creek (A320) in 2001-2002 (Herrera 2004).

Enterococci concentrations varied widely among the tributary sites. For example, base flow enterococci bacteria concentrations ranged from 1 CFU/100 mL in Crisp Creek (F321) to 4,800 CFU/100 mL in Newaukum tributary at Enumclaw (I322B), and storm flow concentrations ranged from 7 CFU/100 mL in Crisp Creek (F321) to 5,740 in Newaukum tributary at SE 424th (B322). Among the tributary sites, the geometric mean enterococci concentration during storm flow was highest (exceeding 3,000 CFU/100 mL) at Newaukum tributary at Enumclaw (I322B). In 2001-2002, geometric mean enterococci concentrations during storm flow exceeded 3,000 CFU/100 mL at Hamm Creek (A307) and the Newaukum tributary at SE 424th (B322).

5.3.3.3 E. Coli *Bacteria*

A measurement of *Escherichia coli* bacteria is used as an indicator to determine the risk to human health from waterborne illnesses in surface waters from the presence of *E. coli,* an enteric bacterium and a member of the group comprising the fecal coliform bacteria. And, as with other

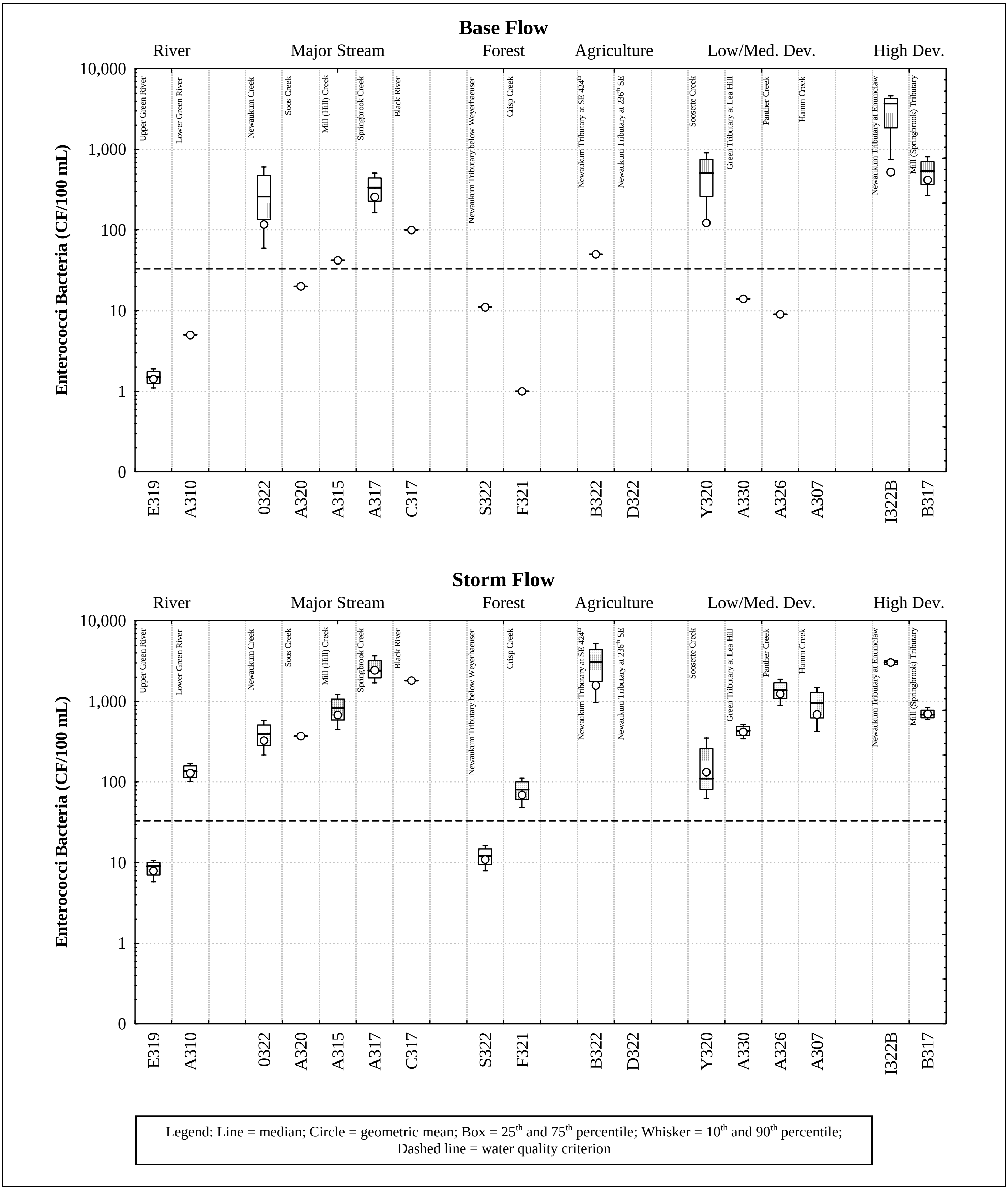


Figure 20. Enterococci bacteria concentrations at sites in the Green-Duwamish watershed in 2003.

fecal coliform bacteria and enterococci, these bacteria are attributed to contamination from the intestinal tract of humans and other warm-blooded animals. Currently, no Washington State surface water quality criteria exist for *E. coli* bacteria in freshwaters. However, the EPA recommends that states use either *E. coli* or enterococci as an indicator for freshwater contamination (U.S. EPA 2002b). The EPA water quality criteria for bacteria in bathing (full body contact) recreational waters specify that the geometric mean of *E. coli* bacteria should not exceed 126 CFU/100 mL during steady-state conditions (U.S. EPA 1986).

Summary statistics for *E. coli* bacteria during base and storm flow are presented in Figure 21 (and Table D3, Appendix D). Base flow *E. coli* concentrations ranged from 0 to 3,700 CFU/100 mL, and storm flow concentrations ranged from 5 to 7,257 CFU/100 mL. During base flow, the EPA criterion was met at all sites except Black River (C317), Panther Creek (A326), Hamm Creek (A307), Mill (Springbrook) tributary (B317), and Newaukum Creek tributaries (D322, B322, and I322B). During storm flow, the EPA criterion was exceeded at all sites except the Upper Green River (E319), Newaukum tributary at Weyerhaeuser (S322), and Crisp Creek (F321). As observed with fecal coliform bacteria and enterococci bacteria, the geometric mean *E. coli* concentration for all the sites was higher during storm flow (300 CFU/100 mL) than during base flow (14 CFU/100 mL).

Spatial pattern analysis results for the Green River showed a significant increasing pattern downstream for *E. coli* bacteria during base flow ($p = 0.0005$) and storm flow ($p = 0.0002$) (Table P7, Appendix P). Between the upper site (E319) and the lower site (A310), the geometric mean of *E. coli* concentrations increased from 0 to 28 CFU/100 mL during base flow, and from 16 to 170 CFU/100 mL during storm flow.

Spatial pattern analysis results for the major stream sites showed there were no significant differences in *E. coli* bacteria concentrations during base flow or storm flow (Tables P8 and P9, Appendix P). Geometric mean base flow *E. coli* bacteria concentrations ranged from 47 CFU/100 mL in Soos Creek (A320) to 262 CFU/100 mL in Black River (C317). Geometric mean storm flow concentrations ranged from 202 CFU/100 mL in Soos Creek (A320) to 1,584 CFU/100 mL in Mill Creek (A315). Similar patterns were observed in 2001-2002 (Herrera 2004).

Of the tributary sites, Newaukum tributary at Enumclaw (I322B) had the maximum base flow *E. coli* concentration (3,700 CFU/100 mL) while the Mill (Springbrook) tributary (B317) had the highest geometric mean base flow *E. coli* concentration (510 CFU/100 mL). Other tributary sites with elevated base flow *E. coli* concentrations include the Newaukum Creek tributary sites B322 and D322, Panther Creek (A326), and Hamm Creek (A307). The lowest geometric mean base flow *E. coli* concentrations among the tributary sites were observed at Crisp Creek (0 CFU/100 mL at F321) and Green tributary at Lea Hill (11 CFU/100 mL at A330). During storm flow, Newaukum tributary sites B322 and D322 (both representing agriculture land use) had the highest geometric mean *E. coli* concentrations (2,912 and 6,600 CFU/100 mL, respectively), and Crisp Creek (F321) had the lowest geometric mean *E. coli* concentration (18 CFU/100 mL) among the tributary sites.

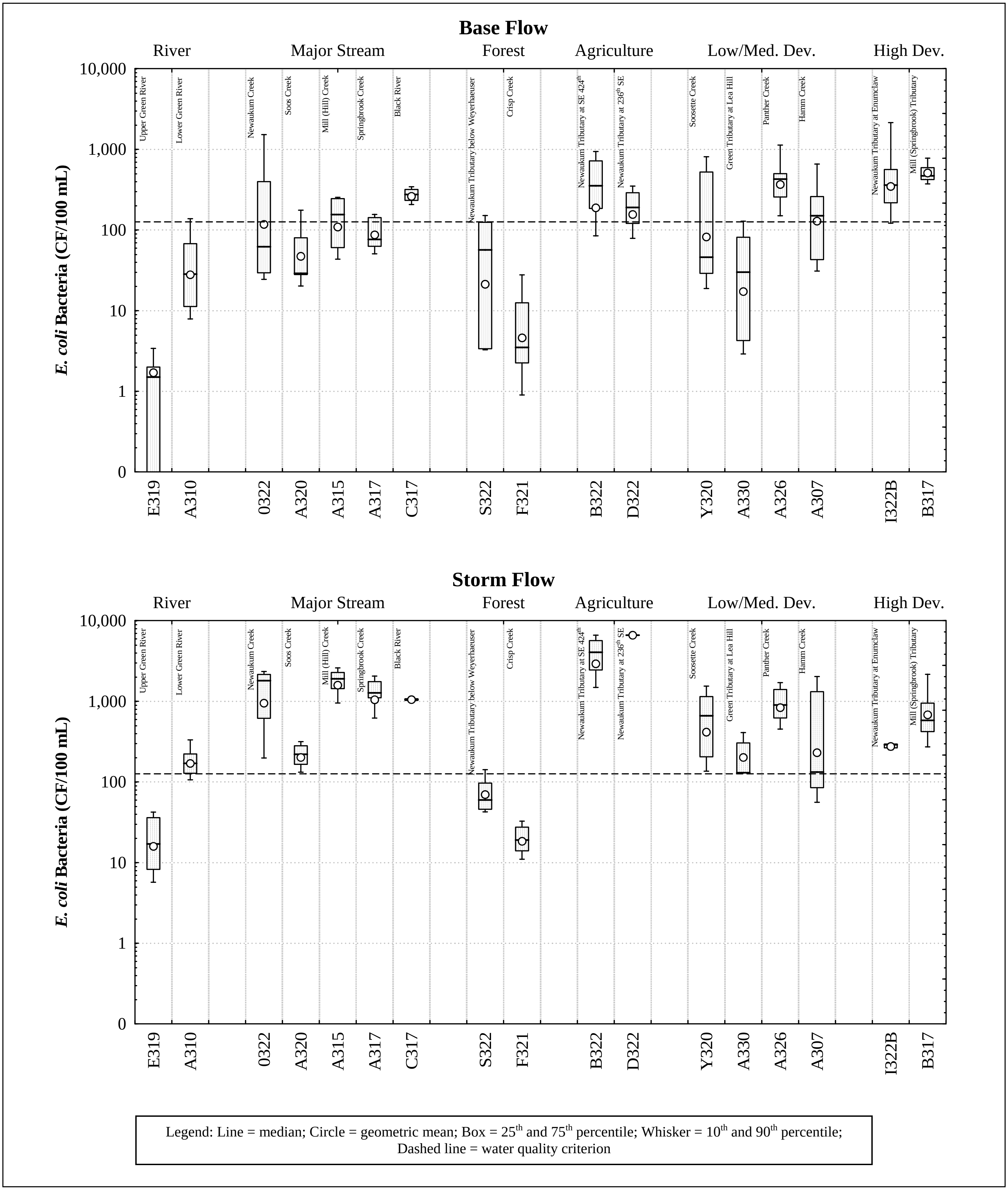


Figure 21. *E. coli* bacteria concentrations at sites in the Green-Duwamish watershed in 2003.

5.3.4 Nutrients

This section summarizes results for nutrients based on the data collected in 2003 for the GDWQA. Summary statistics for these parameters are presented in Appendix E and results from the associated statistical spatial pattern analyses are presented in Appendix P. Nutrients analyzed for the GDWQA include:

- Ammonia nitrogen
- Nitrate+nitrite nitrogen
- Total nitrogen
- Orthophosphate phosphorus
- Total phosphorus.

5.3.4.1 Ammonia Nitrogen

Ammonia nitrogen is of concern in freshwater systems due to its potential toxicity to aquatic life. Within most freshwater systems, ammonia is readily converted to nitrate when oxygen is present. Washington State has surface water quality criteria for chronic and acute ammonia toxicity (WAC 173-201A) that vary depending on the ambient water temperature, pH, and the presence of salmonids (see Table 14). In the following discussion, base flow data are compared to chronic criteria and storm flow data are compared to acute criteria. King County (2000) did not identify ammonia as a possible factor contributing to salmonid decline in Crisp Creek, Newaukum Creek, Soos Creek, Soosette Creek, Mill (Hill) Creek, Springbrook Creek, and the lower and Middle Green River.

Summary statistics for ammonia nitrogen during base and storm flow are presented in Figure 22 (and Table E1, Appendix E). Base flow ammonia nitrogen concentrations ranged from less than 0.010 mg/L (below the detection limit) to 0.970 mg/L, and storm flow ammonia nitrogen concentrations ranged from less than 0.010 mg/L to 0.900 mg/L. The ammonia nitrogen chronic criterion was never exceeded in any sample.

In general, ammonia nitrogen concentrations in the Green River are low. The maximum ammonia concentration (0.047 mg/L) was observed at the lower site during storm flow. Spatial pattern analysis results for the Green River (Table P10, Appendix P) indicate that there is no significant difference in ammonia nitrogen concentrations between upper and lower stream sites during base flow or storm flow.

Among the major stream sites, median base flow ammonia nitrogen concentrations ranged from less than 0.010 mg/L in Soos Creek (A320) and Newaukum Creek (0322) to 0.331 mg/L in the Black River (C317), and median storm flow ammonia nitrogen concentrations ranged from 0.015 mg/L in Soos Creek (A320) to 0.060 mg/L in the Black River (C317) and Mill (Hill) Creek (A315). The spatial pattern analysis results for base flow (Table P11, Appendix P) show that the Black River (C317) had significantly higher ($p = 0.0027$) ammonia nitrogen concentrations relative to Soos Creek (A320). During storm flow (Table P12, Appendix P), no significant difference was detected among the major stream sites.

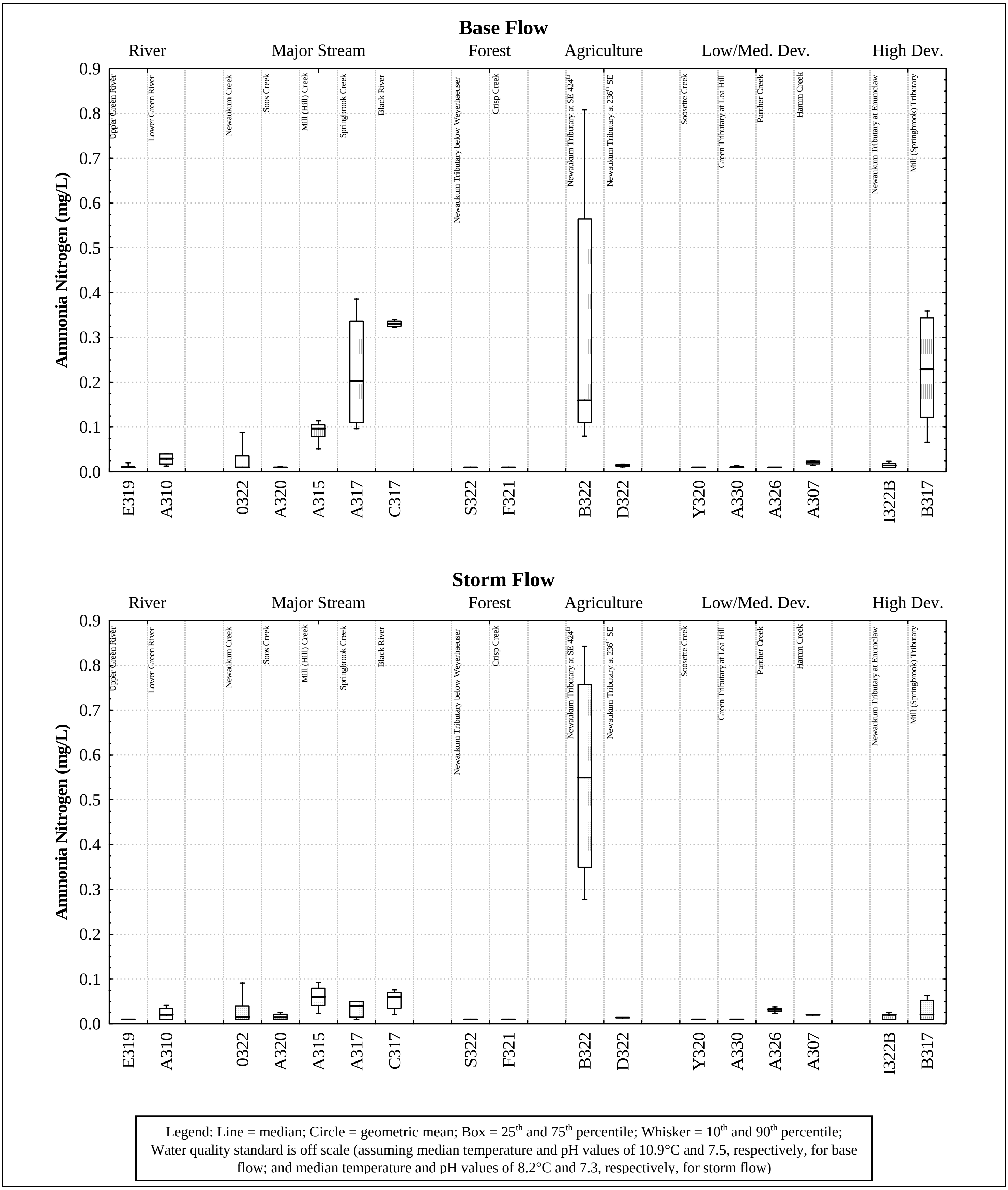


Figure 22. Ammonia nitrogen concentrations at sites in the Green-Duwamish watershed in 2003.

Among the tributary sites, median ammonia nitrogen concentrations ranged from less than or equal to the detection limit (0.010 mg/L) in five tributaries to 0.229 mg/L in Mill (Springbrook) tributary (B317) during base flow, and ranged from less than 0.010 mg/L in four tributaries to 0.550 mg/L in Newaukum tributary at SE 424th (B322) during storm flow. The Newaukum tributary at SE 424th (B322) exhibited the maximum ammonia nitrogen concentration of all sites during base flow (0.970 mg/L) and storm flow (0.900 mg/L). The highest ammonia nitrogen concentration of all sites was also detected at the Newaukum tributary at SE 424th (B322) in 2001-2002. High ammonia nitrogen concentrations at this site are likely related to inputs of animal waste and fertilizer arising from agricultural/pasture land use in the basin.

5.3.4.2 Nitrate+nitrite Nitrogen

Washington State does not have surface water quality criteria for nitrate+nitrite nitrogen. However, nitrate nitrogen is a regulated parameter in state ground water standards (WAC 173-200-040) and state drinking water standards (WAC 246-290-310) for protection of human health. To prevent a potentially fatal blood disorder in infants called “blue baby syndrome”, both standards specify that nitrate nitrogen concentrations shall not exceed 10 mg/L. Nitrate nitrogen is also a concern in freshwater because it may contribute to an overabundant growth of plant life and to the decline of the biological community. The EPA (2000) has recommended a nutrient criterion of 0.26 mg/L for nitrate+nitrite nitrogen in Puget Sound lowland rivers and streams. This criterion was used for comparison to the sampling results and represents a reference condition that is equivalent to the median of 25th percentiles for four seasons using all data compiled from up to 129 rivers and streams in the Puget Sound lowlands subecoregion.

Summary statistics for nitrate+nitrite nitrogen during base and storm flow are presented in Figure 23 (and Table E2, Appendix E). Base flow nitrate+nitrite concentrations ranged from 0.020 to 5.81 mg/L, and storm flow nitrate+nitrite concentrations ranged from 0.090 to 16.3 mg/L. The U.S. EPA criterion (0.26 mg/L) was frequently exceeded at all sites except the Upper Green River (E319) during both base flow and storm flow. The EPA criterion for nitrate+nitrite nitrogen (0.26 mg/L) was exceeded in all base flow samples at 14 sites and in all storm flow samples at 11 sites (see Table E2, Appendix E), suggesting that nitrate+nitrite nitrogen concentrations were moderate to high at most sites during sampling. The median nitrate+nitrite concentration for all the sites was 0.670 mg/L during base flow and during storm flow.

Spatial pattern analysis results show a significant increasing pattern downstream for nitrate+nitrite nitrogen concentrations in the Green River during base flow (p=0.0040) but not during storm flow (Table P10, Appendix P). Between the upper site (E319) and the lower site (A310), median nitrate+nitrite concentrations increased from 0.130 to 0.290 mg/L during base flow. A significant increasing downstream pattern was observed during base flow and storm flow in 2001-2002 (Herrera 2004).

Among the major stream sites, base flow nitrate+nitrite nitrogen concentrations ranged from 0.251 mg/L in the Black River (C317) to 4.30 mg/L in Newaukum Creek (0322), and storm flow concentrations ranged from 0.240 mg/L in the Black River (C317) to 4.55 mg/L in Newaukum Creek (0322). Spatial pattern analysis results for the major stream sites indicate that base flow

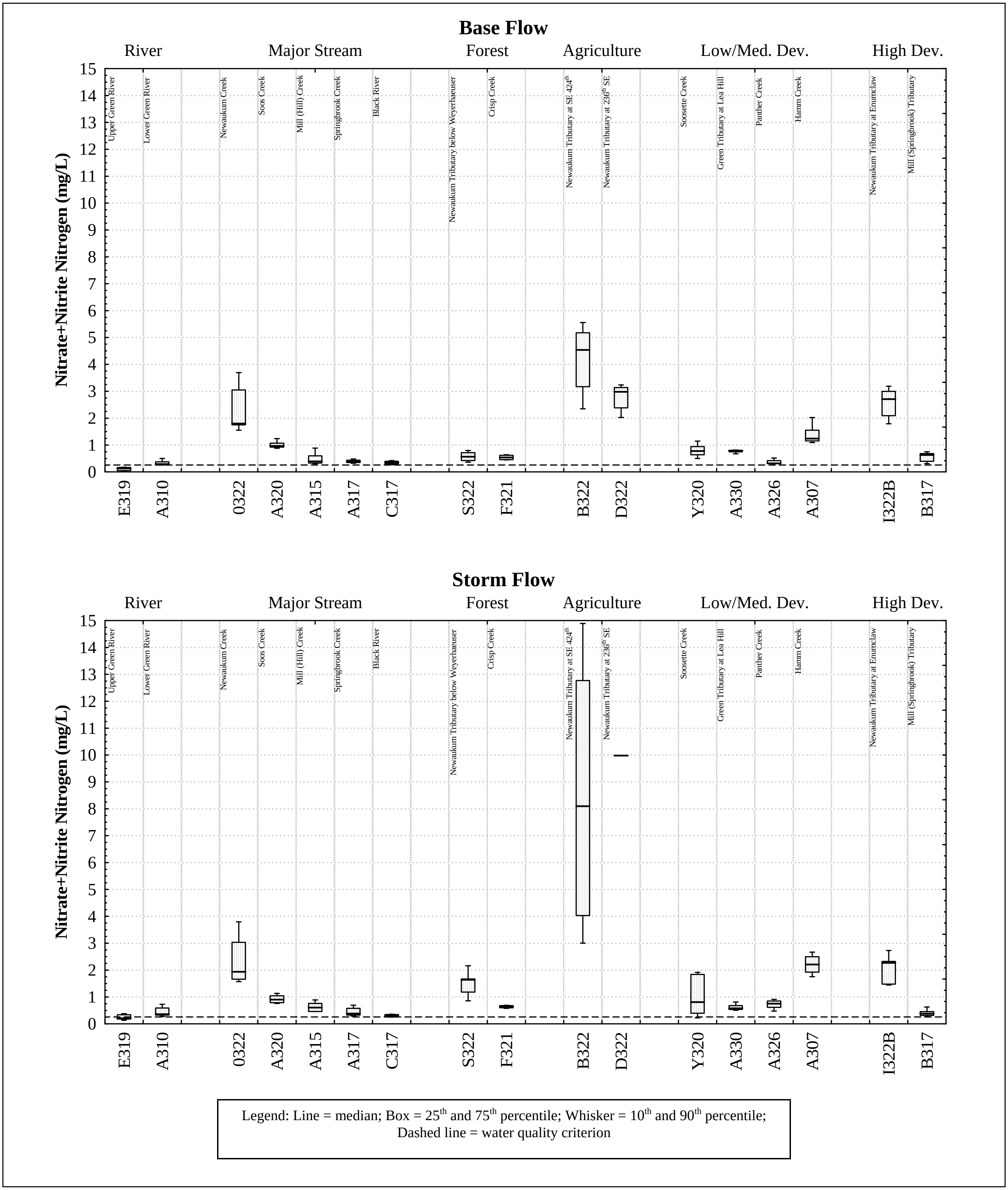


Figure 23. Nitrate+nitrite nitrogen concentrations at sites in the Green-Duwamish watershed in 2003.

nitrate+nitrite concentrations were significantly higher ($p = 0.0012$) in Newaukum Creek (0322) relative to Black River (C317), Springbrook Creek (A317), and Mill (Hill) Creek (A315), and storm flow nitrate+nitrite concentrations were significantly higher ($p = 0.0003$) in Newaukum Creek (0322) relative to Springbrook Creek (A317) and Black River (C317) (Tables P11 and P12, Appendix P). All samples collected from all major stream sites except Black River (C317) exceeded the EPA criterion for nitrate+nitrite nitrogen (0.26 mg/L) during base flow and storm flow.

Among the tributary sites, base flow nitrate+nitrite nitrogen concentrations ranged from 0.290 mg/L in Mill (Springbrook) tributary (B317) to 5.81 mg/L in the Newaukum tributary at SE 424th (B322), and storm flow concentrations ranged from 0.186 mg/L in Mill (Springbrook) tributary (B317) to 16.3 mg/L in the Newaukum tributary at SE 424th (B322). This maximum concentration exceeds the state drinking water criterion of 10 mg/L established for human health purposes. The highest nitrate+nitrite nitrogen concentration of all sites in 2001-2002 was also detected at the Newaukum tributary at SE 424th (B322). The EPA criterion for nitrate+nitrite nitrogen was exceeded in all base flow samples and most storm flow samples collected from the tributary sites (see Table E2, Appendix E)). High nitrate+nitrite nitrogen concentrations at Newaukum tributary at SE 424th (B322) are likely related to inputs of animal waste and fertilizers arising from agricultural/pasture land use in the basin.

5.3.4.3 Total Nitrogen

Currently, Washington State has not established surface water quality criteria for total nitrogen. However, the EPA (2000) has established a nutrient criterion of 0.24 mg/L for total nitrogen in Puget Sound lowland rivers and streams that was used for comparison to these sampling results. This criterion represents a reference condition that is equivalent to the median of 25^{th} percentiles for four seasons using all data from up to 37 rivers and streams in the Puget Sound lowlands subecoregion.

Summary statistics for total nitrogen during base and storm flow are presented in Figure 24 (and Table E3, Appendix E). Base flow total nitrogen concentrations ranged from 0.084 to 6.79 mg/L, and storm flow total nitrogen concentrations ranged from 0.186 to 18.57 mg/L. The EPA criterion for total nitrogen was exceeded in every sample at every site except the Upper Green River (E319) during base flow and storm flow (see Table E3, Appendix E). The median total nitrogen concentration for all sites was 1.04 mg/L during base flow and 1.13 mg/L during storm flow.

Spatial pattern analysis results for the Green River show that total nitrogen concentrations increase significantly downstream during base flow ($p = 0.0040$) and storm flow ($p = 0.0082$) (Table P10, Appendix P). Between the upper site (E319) and the lower site (A310), the median total nitrogen concentration increased from 0.195 to 0.450 mg/L during base flow, and from 0.378 to 0.721 mg/L during storm flow.

Among the major streams, base flow total nitrogen concentrations ranged from 0.987 mg/L in the Black River (C317) to 5.15 mg/L in Newaukum Creek (0322), and storm flow concentrations

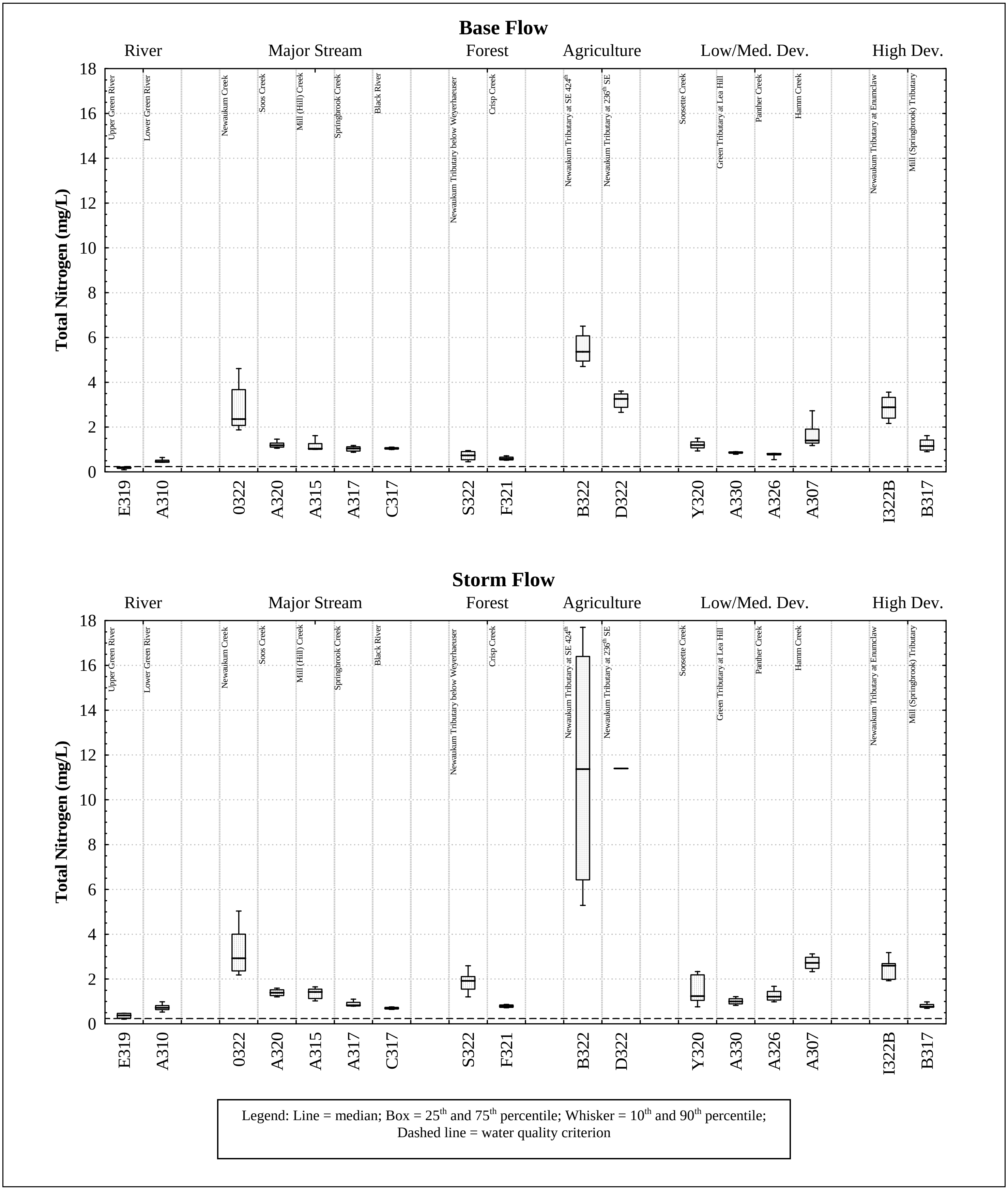


Figure 24. Total nitrogen concentrations at sites in the Green-Duwamish watershed in 2003.

ranged from 0.629 mg/L in Springbrook Creek (A317) to 5.28 mg/L in Newaukum Creek (0322). Spatial pattern analysis results for the major streams show that total nitrogen concentrations in Newaukum Creek (0322) were significantly higher ($p = 0.0041$) relative to the Black River (C317) during base flow, and that Newaukum Creek total nitrogen concentrations were significantly higher ($p = 0.0002$) relative to Springbrook Creek (A317) and the Black River (B317) during storm flow (Tables P11 and P12, Appendix P). All samples collected from the major stream sites exceeded the EPA criterion for total nitrogen (0.24 mg/L) during base flow and storm flow.

Among the tributary sites, median base flow total nitrogen concentrations ranged from 0.587 mg/L in Crisp Creek (F321) to 5.36 mg/L in the Newaukum tributary at SE 424th (B322), and median storm flow concentrations ranged from 0.763 mg/L in Mill (Springbrook) tributary (B317) to 11.37 mg/L in the Newaukum tributary at SE 424th (B322). All samples collected from the tributary sites exceeded the EPA criterion for total nitrogen (0.24 mg/L). As with ammonia nitrogen, high total nitrogen concentrations for Newaukum tributary at SE 424th (B322) were observed in 2001-2002 and are likely related to agricultural/pasture land use in the basin.

5.3.4.4 Orthophosphate Phosphorus

Washington State has not established surface water quality criteria for orthophosphate phosphorus, nor does the EPA have a criterion for orthophosphate phosphorus in streams and rivers. Summary statistics for orthophosphate phosphorus during base and storm flow are presented in Figure 25 (and Table E4, Appendix E). Base flow orthophosphate phosphorus concentrations ranged from 0.003 to 0.860 mg/L, and storm flow concentrations ranged from 0.003 to 2.46 mg/L. The median orthophosphate phosphorus concentration for all the sites was 0.020 mg/L during base flow and 0.014 mg/L during storm flow. At most sites, orthophosphate phosphorus concentrations were moderately low with the exception of the Newaukum tributary at SE 424th (B322) which had the maximum concentration during base flow and storm flow (Table E4, Appendix E). As with other nutrients discussed above, high orthophosphate phosphorus concentrations were observed at this site in 2001-2002 and are likely related to agricultural/pasture land use in this subbasin.

Orthophosphate phosphorus concentrations were generally low in the Green River during base flow and storm flow. Spatial pattern analysis results show that orthophosphate phosphorus concentrations increase significantly downstream during base flow ($p = 0.0040$) and storm flow ($p = 0.0012$) (Table P10, Appendix P). Between the upper site (E319) and the lower site (A310), median concentrations increased from 0.006 to 0.010 mg/L during base flow and from 0.006 to 0.011 mg/L during storm flow. Similar patterns were observed in 2001-2002 (Herrera 2004).

Among the major streams, base flow orthophosphate phosphorus concentrations ranged from 0.010 mg/L in Soos Creek (A320) and Black River (C317) to 0.160 mg/L in Newaukum Creek (0322), and storm flow concentrations ranged from 0.010 mg/L at three sites (Springbrook Creek [A317], Black River [C317], and Soos Creek [A320]) to 0.250 mg/L in Newaukum Creek (0322). The spatial pattern analyses results show that base flow orthophosphate phosphorus

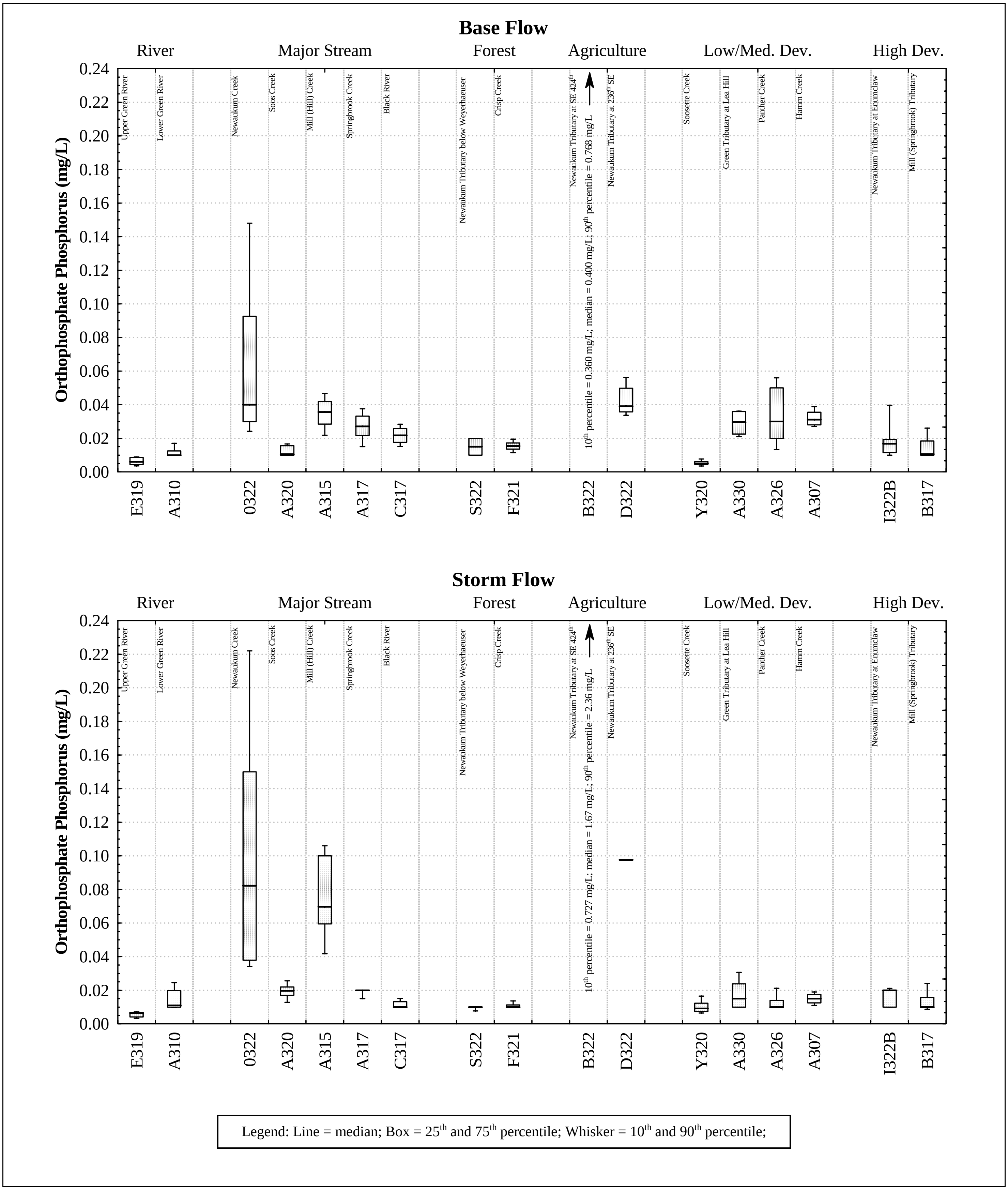


Figure 25. Orthophosphate phosphorus concentrations at sites in the Green-Duwamish watershed in 2003.

concentrations are significantly higher (p = 0.0160) in Newaukum Creek (0322) relative to Soos Creek (A320). Storm flow orthophosphate phosphorus concentrations in Newaukum Creek (0322) are significantly higher (p = 0.0005) relative to Springbrook Creek (A317) and Soos Creek (A320), which are higher relative to the Black River (C317) (Tables P11 and P12, Appendix P).

Among the tributaries, median base flow orthophosphate phosphorus concentrations ranged from 0.005 mg/L in Soosette Creek (Y320) to 0.400 mg/L in the Newaukum tributary at SE 424th (B322), and median storm flow concentrations ranged from 0.009 mg/L in Soosette Creek (Y320) to 1.66 mg/L in the Newaukum tributary at SE 424th (B322). Newaukum tributary at SE 424th (B322) exhibited the maximum orthophosphate phosphorus concentrations of all sampling sites during base flow (0.860 mg/L) and storm flow (2.46 mg/L).

5.3.4.5 Total Phosphorus

Total phosphorus is a concern in freshwater because it can contribute to eutrophication. Currently, Washington State has not established surface water quality criteria for total phosphorus in rivers and streams; however, state criteria have been established for lakes. The EPA (2000) has established a total phosphorus criterion of 0.0195 mg/L for Puget Sound lowland rivers and streams that was used for comparison to these sampling results. This criterion represents a reference condition that is based on the 25th percentile of all data compiled for the Puget Sound lowland ecoregion.

Summary statistics for total phosphorus during base and storm flow are presented in Figure 26 (and Table E5, Appendix E). Base flow total phosphorus concentrations ranged from 0.010 to 0.880 mg/L, and storm flow total phosphorus concentrations ranged from 0.010 to 2.41 mg/L. All sites except the Upper Green River (E319) exceeded the EPA total phosphorus criterion (0.0195 mg/L) during base flow and storm flow. The median total phosphorus concentration for all sites was lower during base flow (0.043 mg/L) than storm flow (0.060 mg/L).

Spatial pattern analysis results for the Green River show a significant increasing pattern downstream for total phosphorus concentrations during base flow (p = 0.0081) and storm flow (p = 0.0140) (Table P10, Appendix P). No significant increasing pattern was observed downstream during storm flow in 2001-2002 (Herrera 2004). Between the upper site (E319) and the lower site (A310), median total phosphorus concentrations increased from 0.011 to 0.030 mg/L during base flow, and increased from 0.014 and 0.060 mg/L during storm flow.

Among the major stream sites, base flow total phosphorus concentrations ranged from 0.020 mg/L in Soos Creek (A320) to 0.240 mg/L in Newaukum Creek (0322), and storm flow concentrations ranged from 0.030 mg/L at Soos Creek (A320) to 0.350 mg/L in Newaukum Creek (0322). Spatial pattern analysis results show that the Black River (C317) has significantly higher (p = 0.0102) total phosphorus concentrations relative to Soos Creek (A320) and Newaukum Creek (0322) during base flow; and that Mill (Hill) Creek (A315) has significantly higher (p = 0.0180) total phosphorus concentrations relative to Soos Creek (A320) during storm flow (Tables P11 and P12, Appendix P). Median base flow concentrations ranged from 0.023

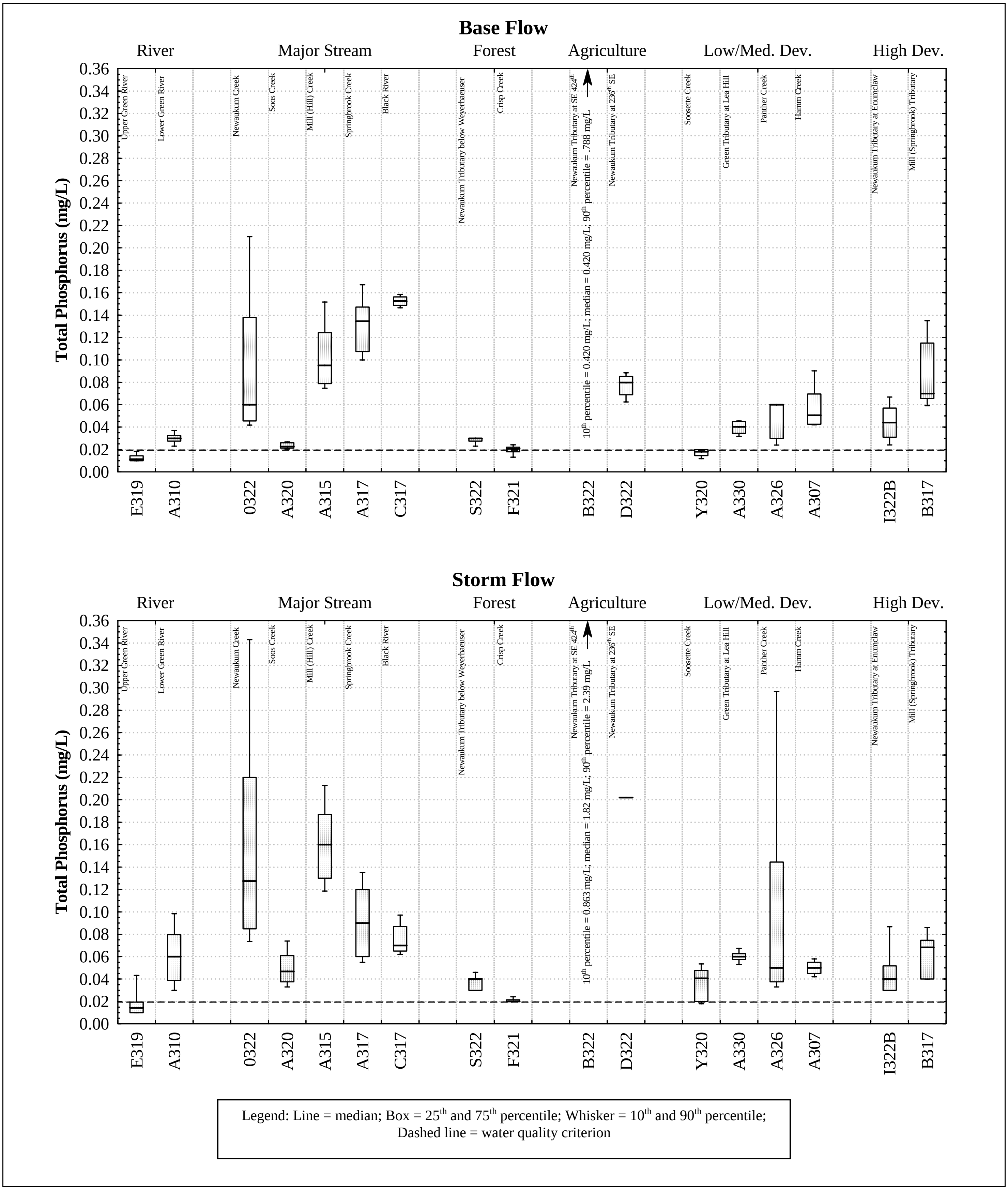


Figure 26. Total phosphorus concentrations at sites in the Green-Duwamish watershed in 2003.

mg/L in Soos Creek (A320) to 0.153 mg/L in the Black River (C317), and median storm flow concentrations ranged from 0.047 mg/L in Soos Creek (A320), to 0.160 mg/L in Mill (Hill) Creek (A315). All base and storm flow samples collected at the major stream sites exceeded the EPA criterion of 0.0195 mg/L.

Among the tributary sites, median base flow total phosphorus concentrations ranged from 0.018 mg/L in Soosette Creek (A320) to 0.420 mg/L in the Newaukum tributary at SE 424th (B322), and median storm flow concentrations ranged from 0.020 mg/L in Crisp Creek (F321) to 1.82 mg/L in the Newaukum tributary at SE 424th (B322). Newaukum tributary at SE 424th (B322) exhibited the maximum total phosphorus concentration of all the sites during base flow (0.880 mg/L) and storm flow (2.41 mg/L). Eight of the 10 tributary sites exceeded the EPA criterion 100 percent of the time during base flow and storm flow sampling (see Table E5, Appendix E).

5.3.5 Metals

This section summarizes results for metals based on the data collected in 2003 for the GDWQA. Summary statistics for the following metals are presented in Appendix F and results from associated statistical spatial pattern analyses are presented in Appendix P:

- Aluminum
- Arsenic
- Cadmium
- Chromium
- Copper
- Lead
- Mercury
- Nickel
- Selenium
- Silver
- Zinc.

5.3.5.1 Aluminum

Summary statistics for dissolved aluminum during base and storm flow are presented in Figure 27 (and Table F1, Appendix F). Summary statistics for total aluminum during base and storm flow are presented in Figure 28 (and Table F2, Appendix F). Aluminum is not included in the Washington State surface water quality standards (WAC 173-201A). However, the EPA (2002a) has established surface water quality criteria for total aluminum that include an acute criterion of 750 µg/L and a chronic criterion of 87 µg/L (see Table 15), which were used herein for comparison to storm flow and base flow results, respectively. It is important to recognize that EPA acknowledges that these criteria may be overprotective. This is because the digestion procedure for analyzing total aluminum includes some aluminum that is not toxic and would not likely be converted to a toxic form under natural conditions (U.S. EPA 1988).

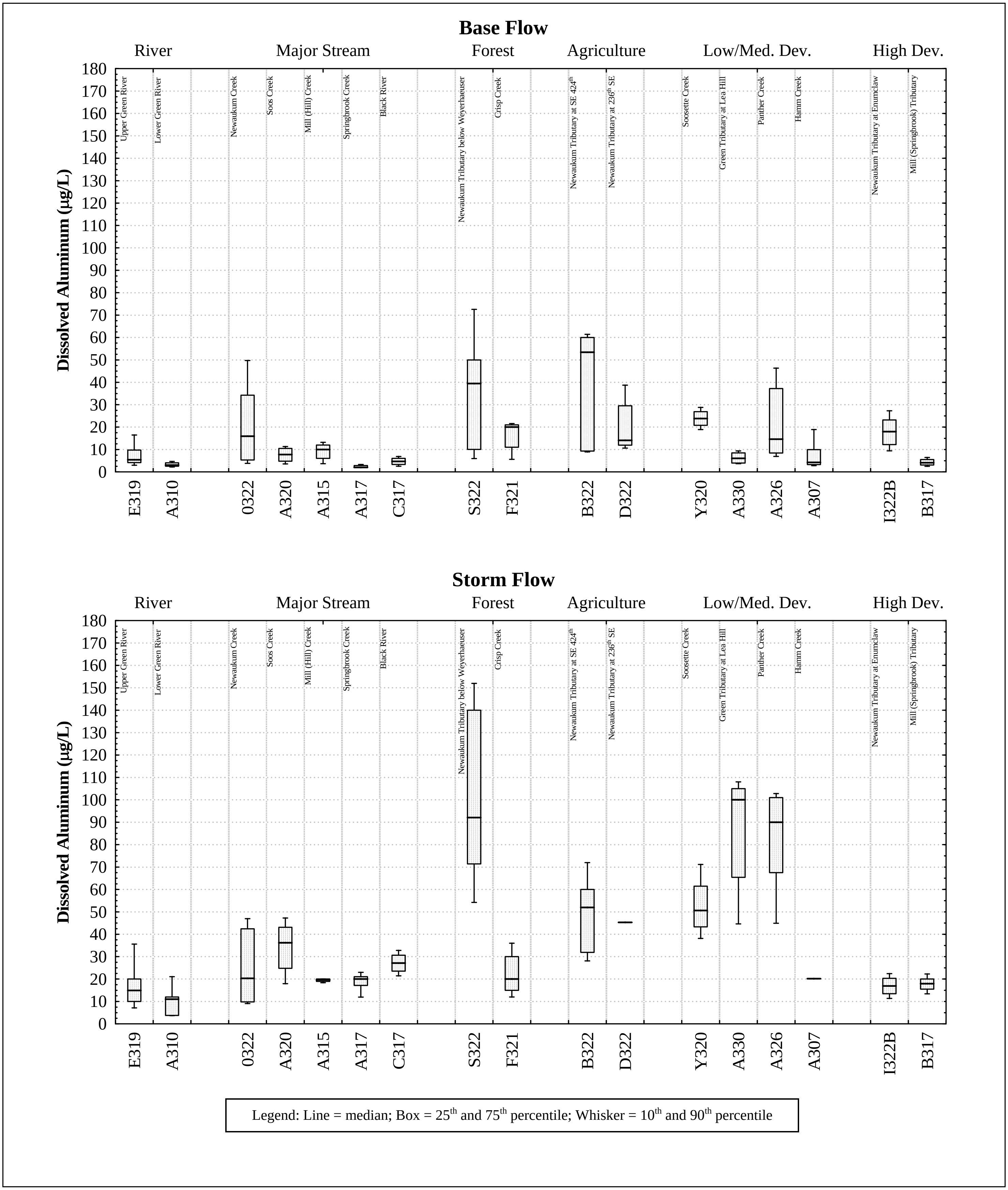


Figure 27. Dissolved aluminum concentrations at sites in the Green-Duwamish watershed in 2003.

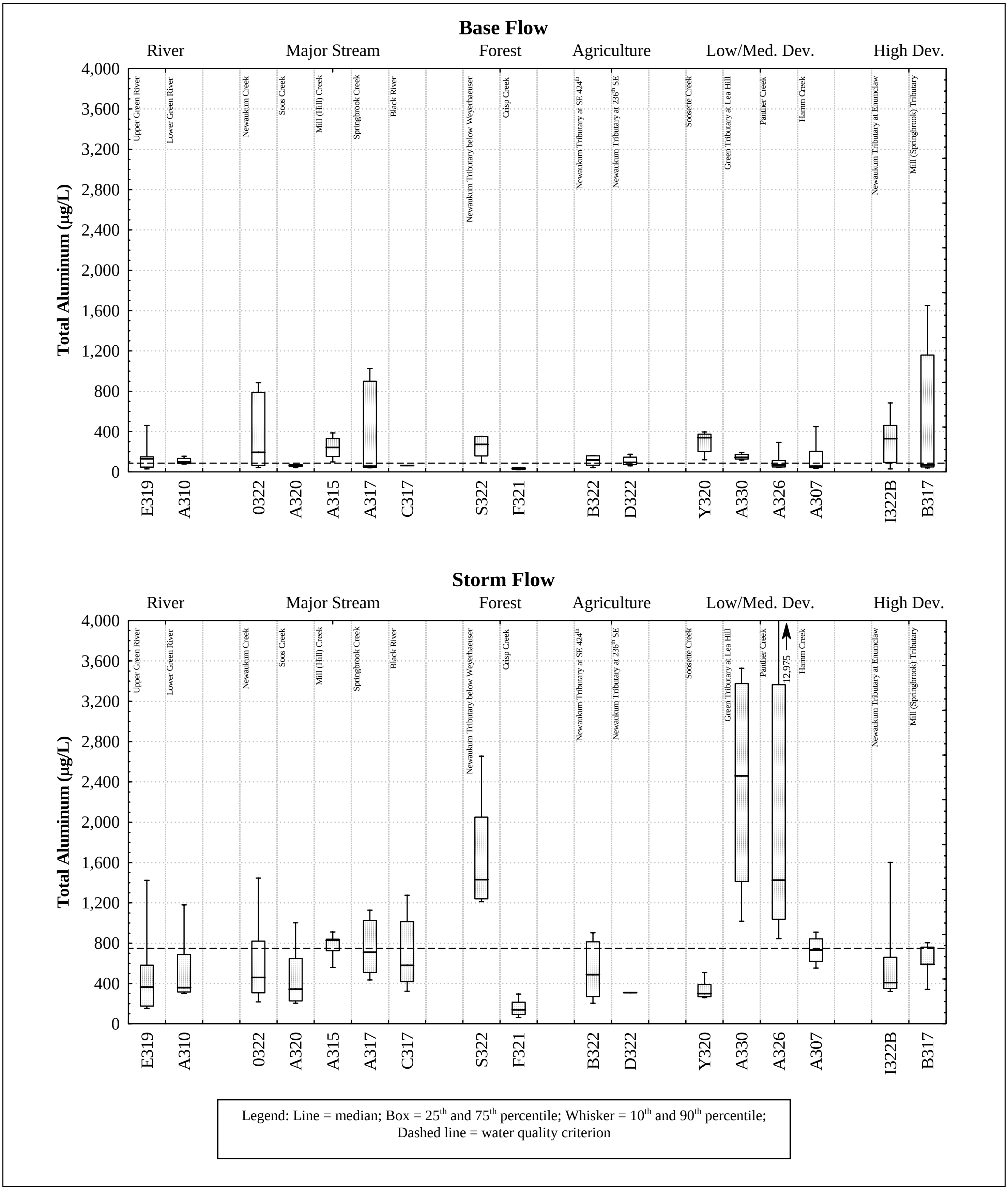


Figure 28. Total aluminum concentrations at sites in the Green-Duwamish watershed in 2003.

For all sites, dissolved aluminum concentrations ranged from less than 2 to 88 µg/L during base flow, and from 4 to 160 µg/L during storm flow. Total aluminum concentrations ranged from 19 to 1,980 µg/L during base flow, and from 43 to 22,000 µg/L during storm flow. During base flow sampling, the chronic criterion for total aluminum was exceeded at all sites except Soos Creek (A320), the Black River (C317), and Crisp Creek (F321). During storm flow sampling, the acute criterion was exceeded at all sites except Newaukum tributary at 236th SE (D322). The median total aluminum concentration for all sites was higher during storm flow (590 µg/L) than during base flow (95 µg/L).

Spatial pattern analysis results for the Green River show that neither dissolved aluminum nor total aluminum concentrations were significantly different from the Upper Green (E319) to the Lower Green (A310) during storm flow or base flow. In 2001-2002, dissolved aluminum concentrations were significantly lower downstream during storm flow, whereas total aluminum concentrations significantly increased from the upper to lower site during base flow. Among all sites, the Mill (Springbrook) tributary (B317) exhibited the maximum base flow total aluminum concentration (1,980 µg/L). The highest median base flow total aluminum concentration was found at Soosette Creek (Y320) (340 µg/L).

Among the major stream sites, there were no significant differences in total or dissolved aluminum concentrations during base flow or storm flow (Tables P14 and P15, Appendix P). Among the tributary sites, median dissolved and total aluminum concentrations were highest during storm flow at the Green tributary at Lea Hill (A330). Elevated total aluminum concentrations were also observed during storm flow at Newaukum tributary below Weyerhaeuser (S322) and Panther Creek (A326).

5.3.5.2 Arsenic

Summary statistics for dissolved arsenic during base and storm flow are presented in Figure 29 (and Table F3, Appendix F). Summary statistics for total arsenic during base and storm flow are presented in Figure 30 (and Table F4, Appendix F). Washington State surface water quality standards (WAC 173-201A) for arsenic include an acute criterion of 360 µg/L and a chronic criterion of 190 µg/L for dissolved arsenic that were used for comparison to storm flow and base flow results, respectively (see Table 14). Dissolved arsenic concentrations did not exceed the criteria at any site during either base flow or storm flow.

Dissolved arsenic concentrations ranged from less than 0.2 to 1.2 µg/L during base flow, and ranged from less than 0.2 to 1.4 µg/L during storm flow. Total arsenic concentrations ranged from less than 0.3 to 2.0 µg/L during base flow, and from less than 0.3 to 5.7 µg/L during storm flow. The median total arsenic concentration (0.9 µg/L) for all sites was the same during storm flow and base flow.

Spatial pattern analysis results for the Green River showed no significant difference in dissolved arsenic from the upper to lower sites during either base flow or storm flow (Table P13, Appendix P). Total arsenic concentrations showed a significant increasing downstream pattern

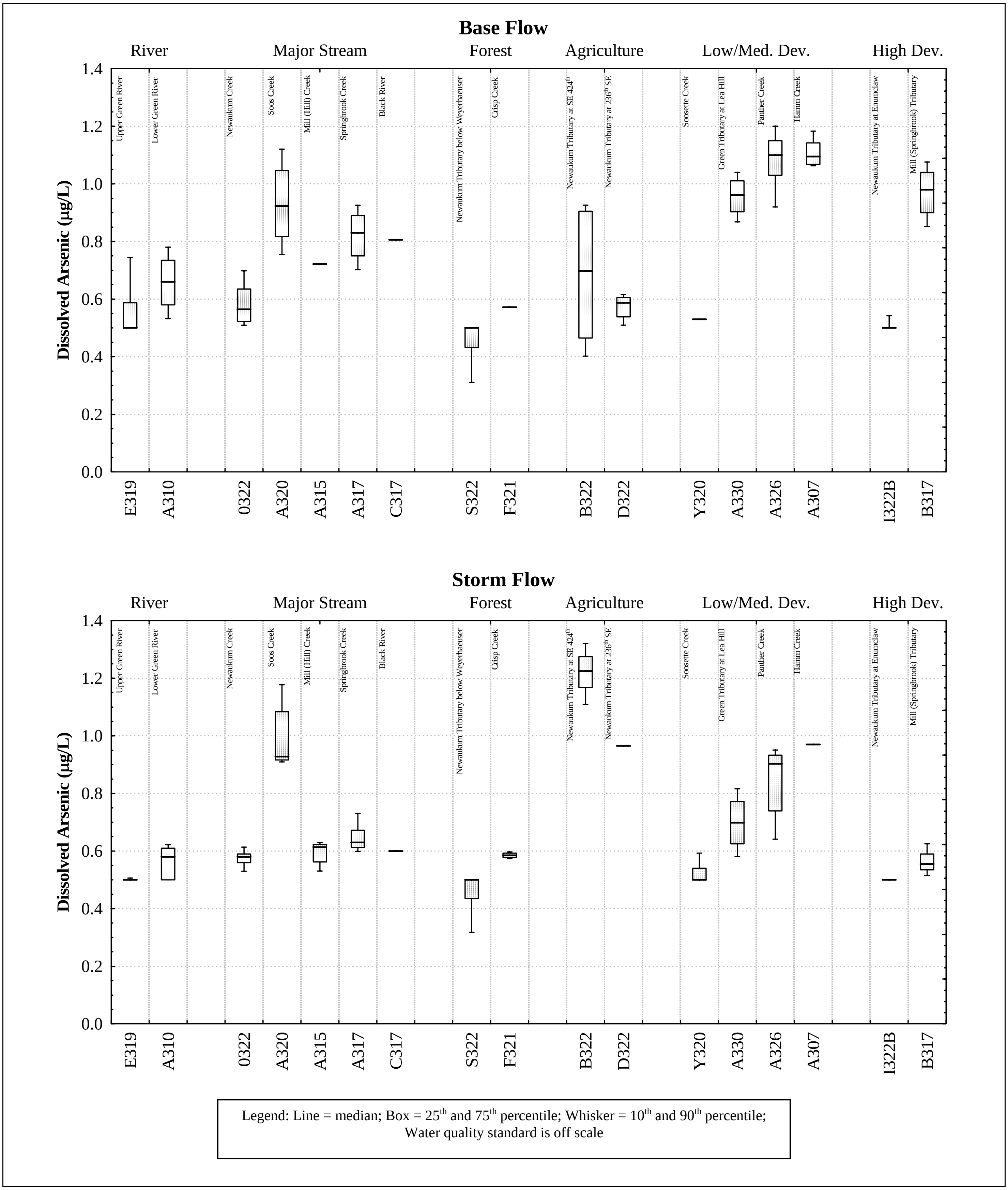


Figure 29. Dissolved arsenic concentrations at sites in the Green-Duwamish watershed in 2003.

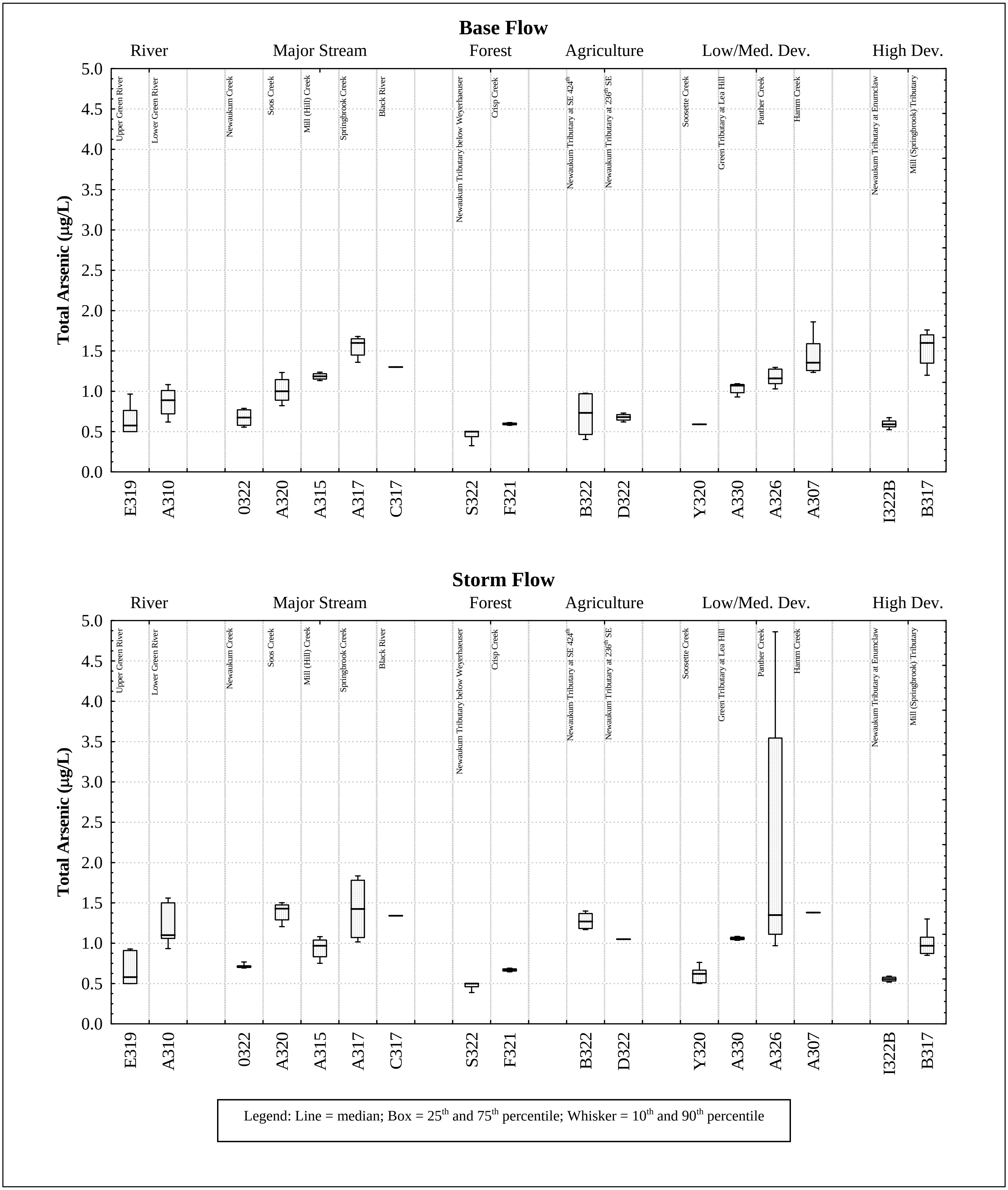


Figure 30. Total arsenic concentrations at sites in the Green-Duwamish watershed in 2003.

during storm flow ($p = 0.0317$), but not during baseflow. The median total arsenic concentration increased downstream, from 0.6 to 1.1 µg/L during storm flow.

Results of the spatial pattern analysis for the remaining major stream sites (Tables P14 and P15, Appendix P) show that Springbrook Creek (A317) had significantly higher ($p = 0.0272$) dissolved arsenic concentrations relative to Newaukum Creek (0322) during base flow, and Soos Creek (A320) had significantly higher dissolved and total arsenic concentrations relative to Newaukum Creek (0322) during storm flow ($p = 0.0283$ and 0.0215, respectively). Too few samples were collected from the Black River (C317) for inclusion in the statistical analysis.

The tributary sites exhibited dissolved arsenic concentrations that were similar to those for the major stream sites. Among the tributary sites, the highest dissolved arsenic concentrations were observed during storm flow at the Newaukum tributary at SE 424th (B322) and the highest total arsenic concentrations were observed during storm flow at Panther Creek (A326).

5.3.5.3 Cadmium

Summary statistics for dissolved cadmium during base and storm flow are presented in Figure 31 (and Table F5, Appendix F). Summary statistics for total cadmium during base and storm flow are presented in Figure 32 (and Table F6, Appendix F). Washington State surface water quality standards (WAC 173-201A) include acute and chronic criteria for dissolved cadmium that vary with hardness (see Table 14). None of the sample values exceeded the state chronic criterion during base flow or the state acute criterion during storm flow.

Dissolved cadmium concentrations ranged from less than 0.01 to 0.10 µg/L during base flow, and from less than 0.01 to 0.11 µg/L during storm flow. Total cadmium concentrations ranged from less than 0.01 to 0.10 µg/L during base flow, and ranged from less than 0.01 to 0.32 µg/L during storm flow. The median dissolved cadmium concentration for all sites was equivalent (0.10 µg/L) during both base flow and storm flow, which is primarily the result of using the detection limit for undetected values and the low percentages of detected values (i.e., 5 percent of all base flow values and 16 percent of all storm flow values were detected).

Spatial pattern analysis results for the Green River show that total and dissolved cadmium concentrations did not differ significantly between the upper and lower sites during base flow or storm flow (Table P13, Appendix P). Dissolved and total cadmium concentrations were significantly different among some major stream sites (Tables P14 and P15, Appendix P), but the observed differences were primarily due to varying detection limits (ranging from 0.01 to 0.1 µg/L) for the analyzed samples.

The tributary sites exhibited cadmium concentrations that were similar to those for the major stream sites. As observed in 2001-2002, total cadmium concentrations were highest at Mill (Springbrook) tributary (B317) during storm flow.

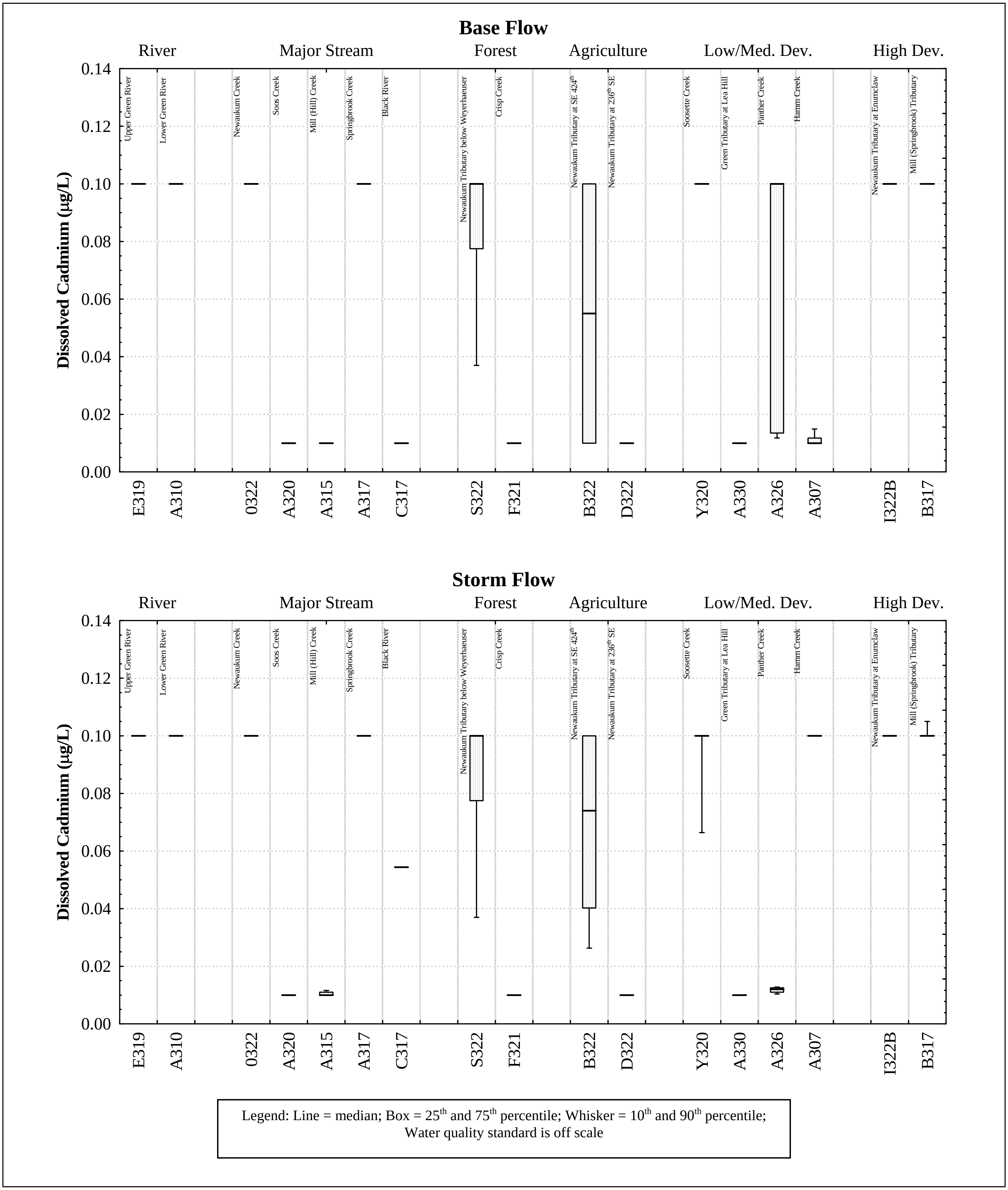


Figure 31. Dissolved cadmium concentrations at sites in the Green-Duwamish watershed in 2003.

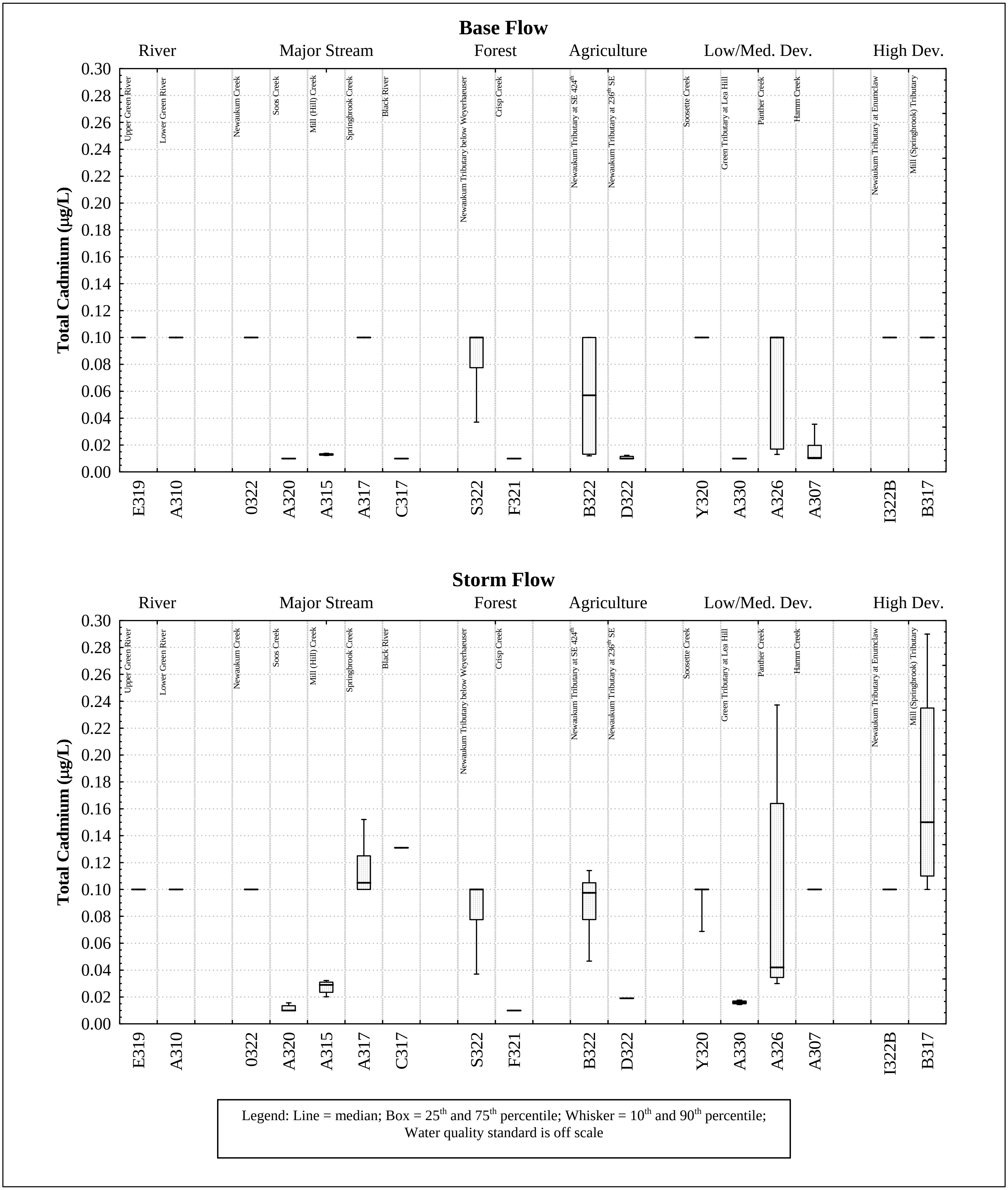


Figure 32. Total cadmium concentrations at sites in the Green-Duwamish watershed in 2003.

5.3.5.4 Chromium

Summary statistics for dissolved chromium during base and storm flow are presented in Figure 33 (and Table F7, Appendix F). Summary statistics for total chromium during base and storm flow are presented in Figure 34 (and Table F8, Appendix F). Washington State surface water quality standards (WAC 173-201A) include acute and chronic criteria for total chromium (or trivalent chromium if available) that vary with hardness (see Table 14). None of the sample values for all monitoring sites exceeded the state chronic criterion during base flow or the acute criterion during storm flow.

Dissolved chromium concentrations ranged from less than 0.05 to 0.77 µg/L, and ranged from less than 0.13 to 0.185 µg/L during storm flow. Total chromium concentrations ranged from less than 0.10 to 1.73 µg/L during base flow, and from 0.25 to 32.8 µg/L during storm flow. The median total chromium concentration for all sites was higher during storm flow (0.80 µg/L) than during base flow (0.040 µg/L).

Spatial pattern analysis results for the Green River show no significant differences in dissolved or total chromium concentrations between the upper and lower sites during base flow or storm flow (Table P13, Appendix P).

Among the major streams, dissolved chromium concentrations were significantly higher ($p = 0.0245$) in Newaukum Creek (0322) relative to Soos Creek (A320) during base flow (Table P14 Appendix P). During storm flow, dissolved chromium concentrations were significantly higher ($p = 0.0059$) in Springbrook Creek (A317) relative to Soos Creek (A320) and Mill Creek (A315) (Table P15 (Appendix P). Total chromium concentrations did not differ significantly among the major streams during base flow, but were significantly higher ($p = 0.0299$) during storm flow at Springbrook Creek (A317) relative to Newaukum Creek (0322). The tributary sites exhibited chromium concentrations that were similar to those observed at the major stream sites.

5.3.5.5 Copper

Summary statistics for dissolved copper during base and storm flow are presented in Figure 35 (and Table F9, Appendix F). Summary statistics for total copper during base and storm flow are presented in Figure 36 (and Table F10, Appendix 10). Washington State surface water quality standards (WAC 173-201A) include acute and chronic criteria for dissolved copper that vary with hardness (see Table 14). The chronic criterion was never exceeded during base flow sampling, and the acute criterion was never exceeded during storm flow sampling at all monitoring sites.

Dissolved copper concentrations ranged from 0.2 to 6.3 µg/L during base flow, and ranged from 0.2 to 8.2 µg/L during storm flow. Total copper concentrations ranged from 0.3 to 11.3 µg/L during base flow, and ranged from 0.3 to 33.2 µg/L during storm flow. Among all sites, the median dissolved copper concentration was higher during storm flow (1.9µg/L) than during base flow (1.0 µg/L), and the median total copper concentration was also higher during storm flow (3.3 µg/L) than during base flow (1.2 µg/L).

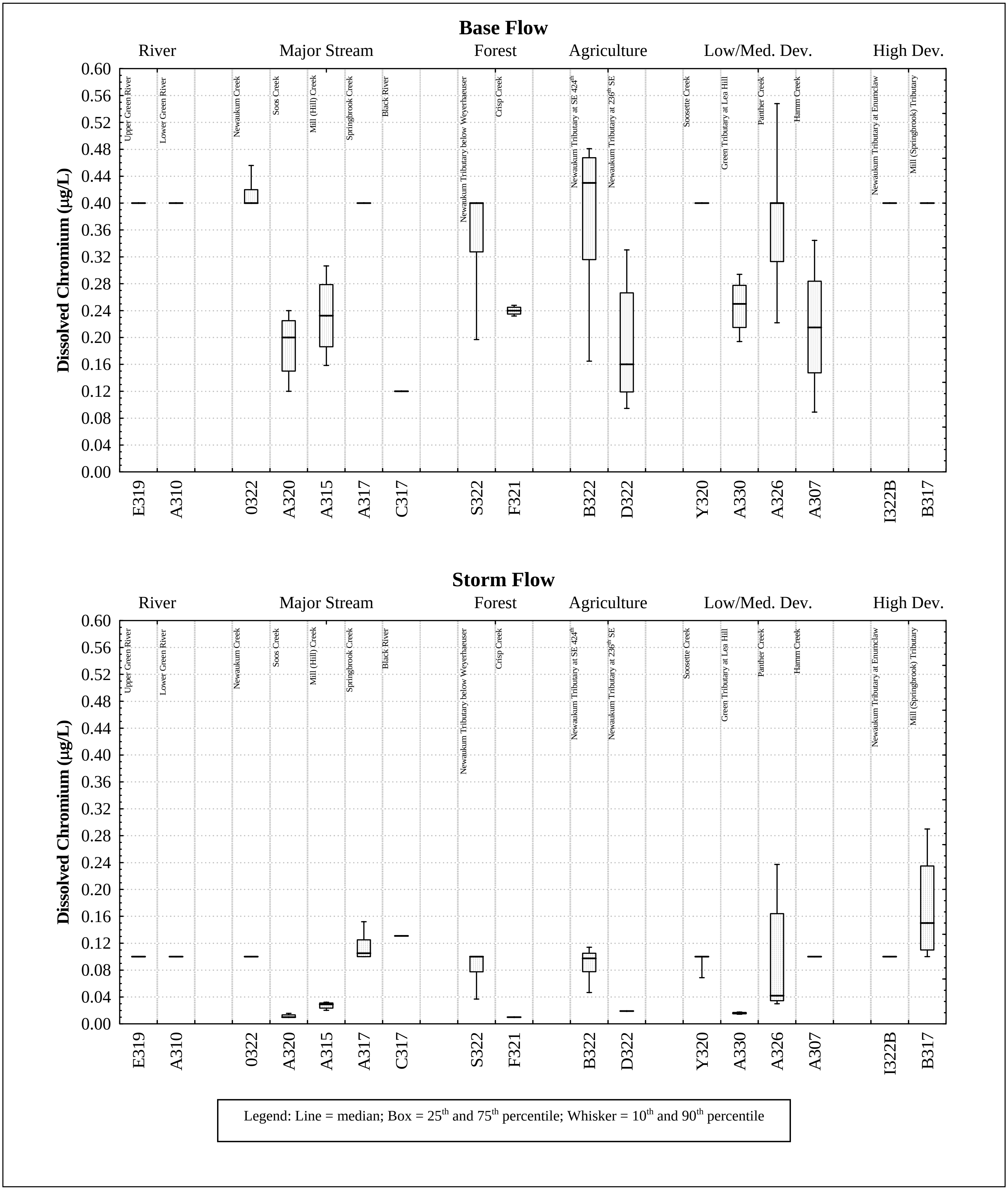
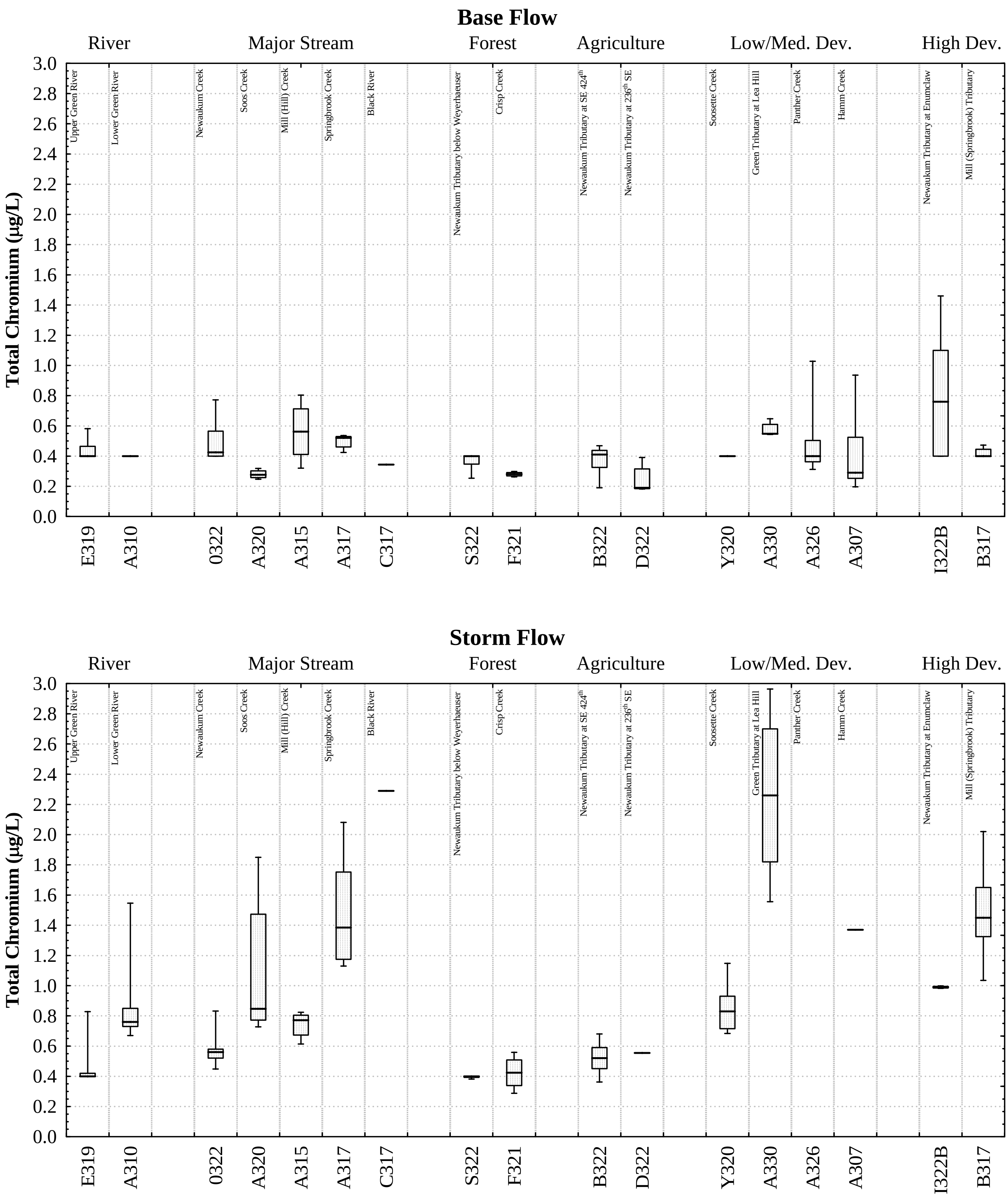


Figure 33. Dissolved chromium concentrations at sites in the Green-Duwamish watershed in 2003.



Legend: Line = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile;
Water quality standard is off scale (assuming median hardness values of 60.7 and 41.0 mg/L as $CaCO_3$ for base and storm flow, respectively)

Figure 34. Total chromium concentrations at sites in the Green-Duwamish watershed in 2003.

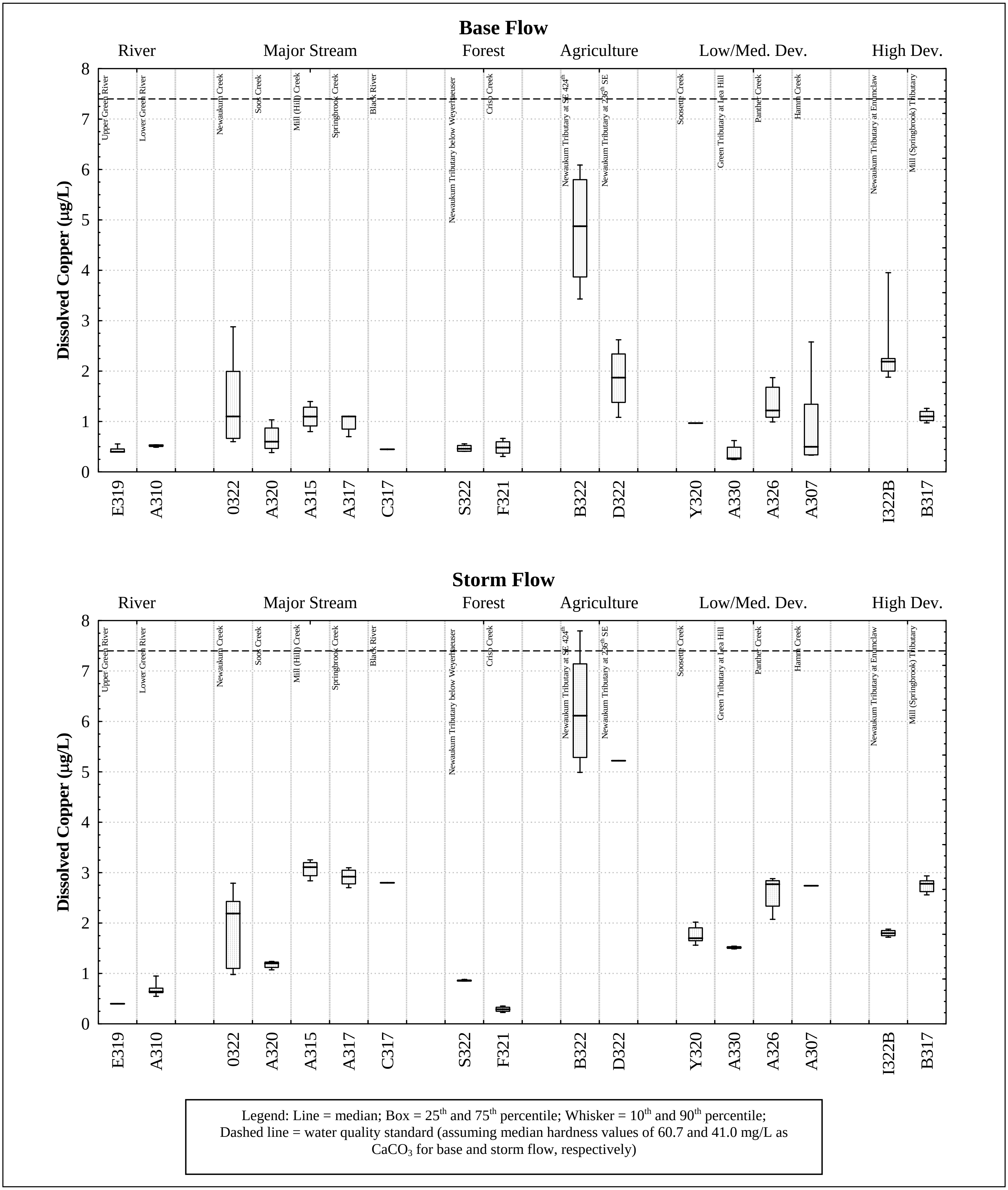


Figure 35. Dissolved copper concentrations at sites in the Green-Duwamish watershed in 2003.

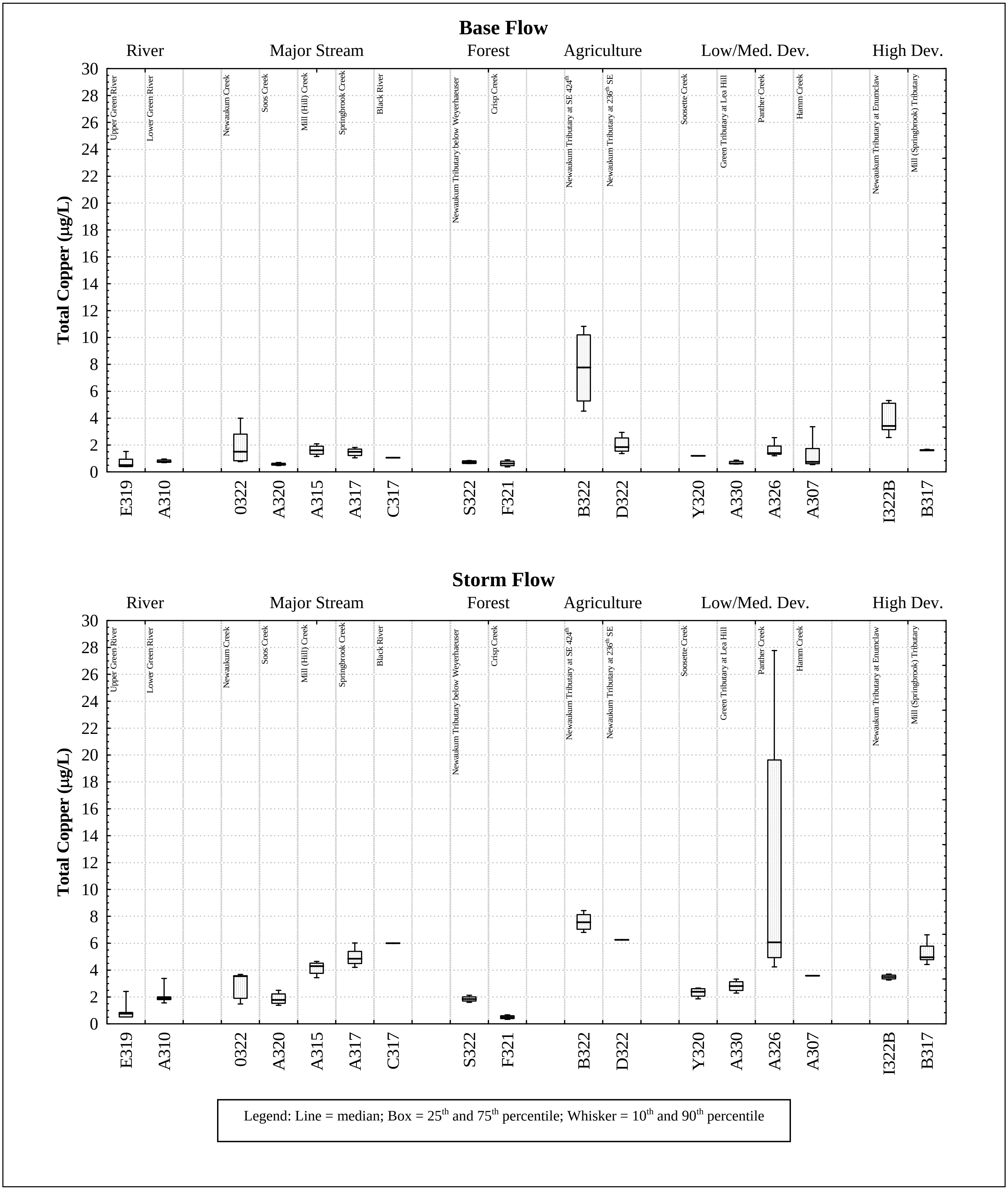


Figure 36. Total copper concentrations at sites in the Green-Duwamish watershed in 2003.

Spatial pattern analysis results for the Green River show that dissolved copper concentrations significantly increased from the upper site to lower site during storm flow ($p = 0.0079$), but not during base flow (Table P13, Appendix P). The median dissolved copper concentration at the upper site was 0.4 µg/L at the upper site and 0.6 µg/L at the lower site during storm flow. There were no significant differences in total copper concentrations during either base flow or storm flow, whereas total copper concentrations were observed to significantly increase downstream during base flow in 2001-2002 (Hererra 2004).

Among the major streams, there were no significant differences in dissolved or total copper concentrations during base flow (Table P14, Appendix P). During storm flow, dissolved copper concentrations were significantly higher ($p=0.0392$) in Mill (Hill) Creek (A315) relative to Soos Creek (A320), and total copper concentrations were significantly higher ($p = 0.0224$) in Springbrook Creek (A317) relative to Soos Creek (A320).

Among the tributary sites, median dissolved and total copper concentrations were highest at Newaukum tributary at SE 124th (B322) during base flow and storm flow. During storm flow, median dissolved copper concentrations were also elevated at the Newaukum tributary at 236th SE (D322), and median total copper concentrations were also elevated at the Newaukum tributary at SE 236th (D322) and Panther Creek (A326).

5.3.5.6 Lead

Summary statistics for dissolved lead during base and storm flow are presented in Figure 37 (and Table F11, Appendix F). Summary statistics for total lead during base and storm flow are presented in Figure 38 (and Table F12, Appendix F). Washington State surface water quality standards (WAC 173-201A) include acute and chronic criteria for dissolved lead that vary with hardness (see Table 14). None of the sample values exceeded the state chronic criterion during base flow or the acute criterion during storm flow.

Dissolved lead concentrations ranged from less than 0.025 to 0.362 µg/L during base flow, and from less than 0.025 to 0.385 µg/L during storm flow. Total lead concentrations ranged from 0.028 to 5.50 µg/L during base flow, and from 0.031 to 38.30 µg/L during storm flow. Among all sites, the median dissolved lead concentration was the same during storm flow and base flow (0.200 µg/L). The median total lead concentration was higher during storm flow (0.420 µg/L) than base flow (less than 0.200 µg/L).

Spatial pattern analysis for the Green River sites show that neither dissolved lead nor total lead concentrations differed significantly between the upper and lower sites (Table P13, Appendix P). In 2001-2002, total lead concentrations increased significantly downstream during storm flow (Herrera 2004).

Based on results of the spatial pattern analysis for the major streams, dissolved lead concentrations during base flow were significantly higher ($p=0.0142$) at Newaukum Creek (0322) relative to Mill (Hill) Creek (A315) (Table P14, Appendix P). However, this test result is due to the different detection limits reported for samples collected from the two sites. There

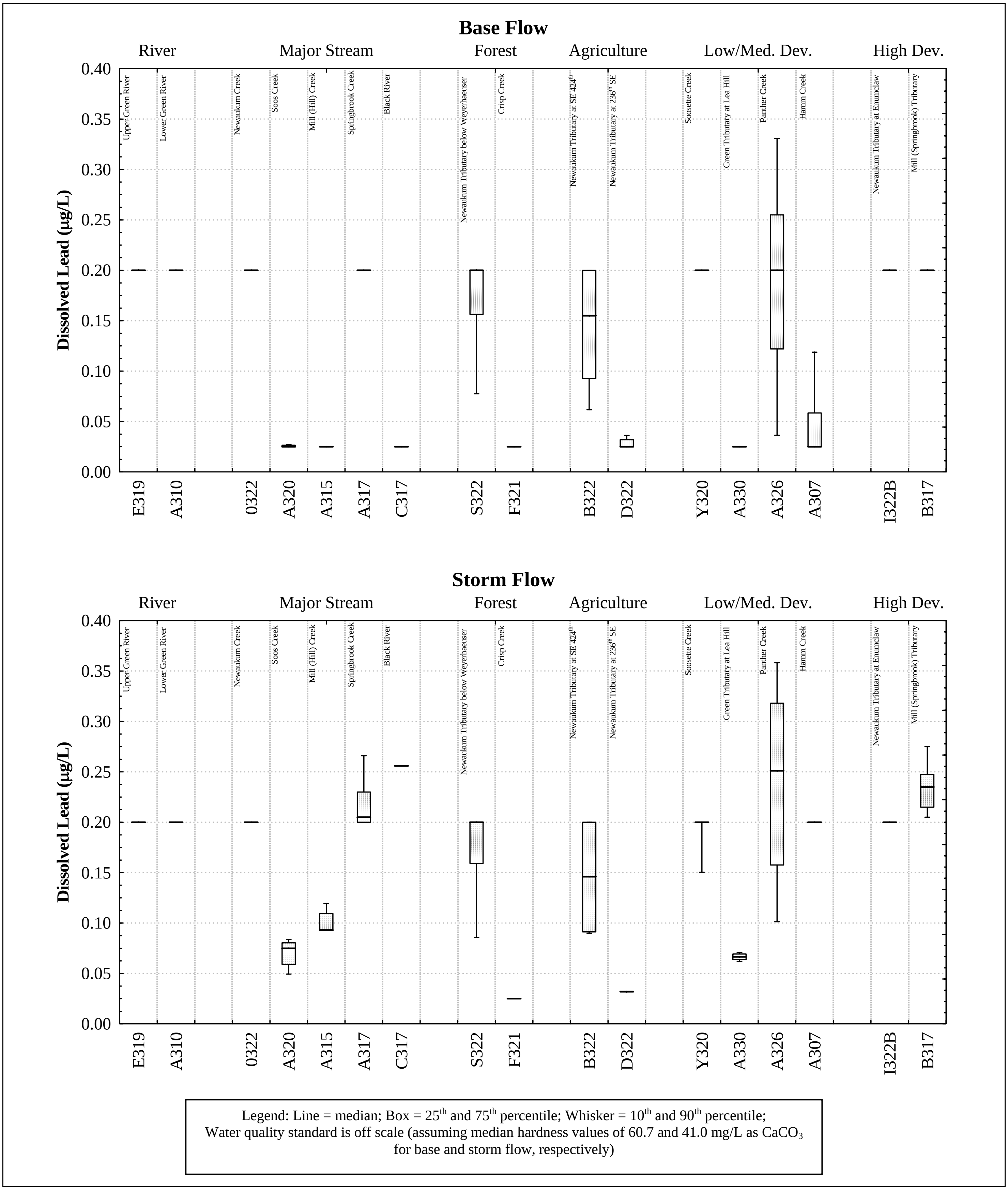


Figure 37. Dissolved lead concentrations at sites in the Green-Duwamish watershed in 2003.

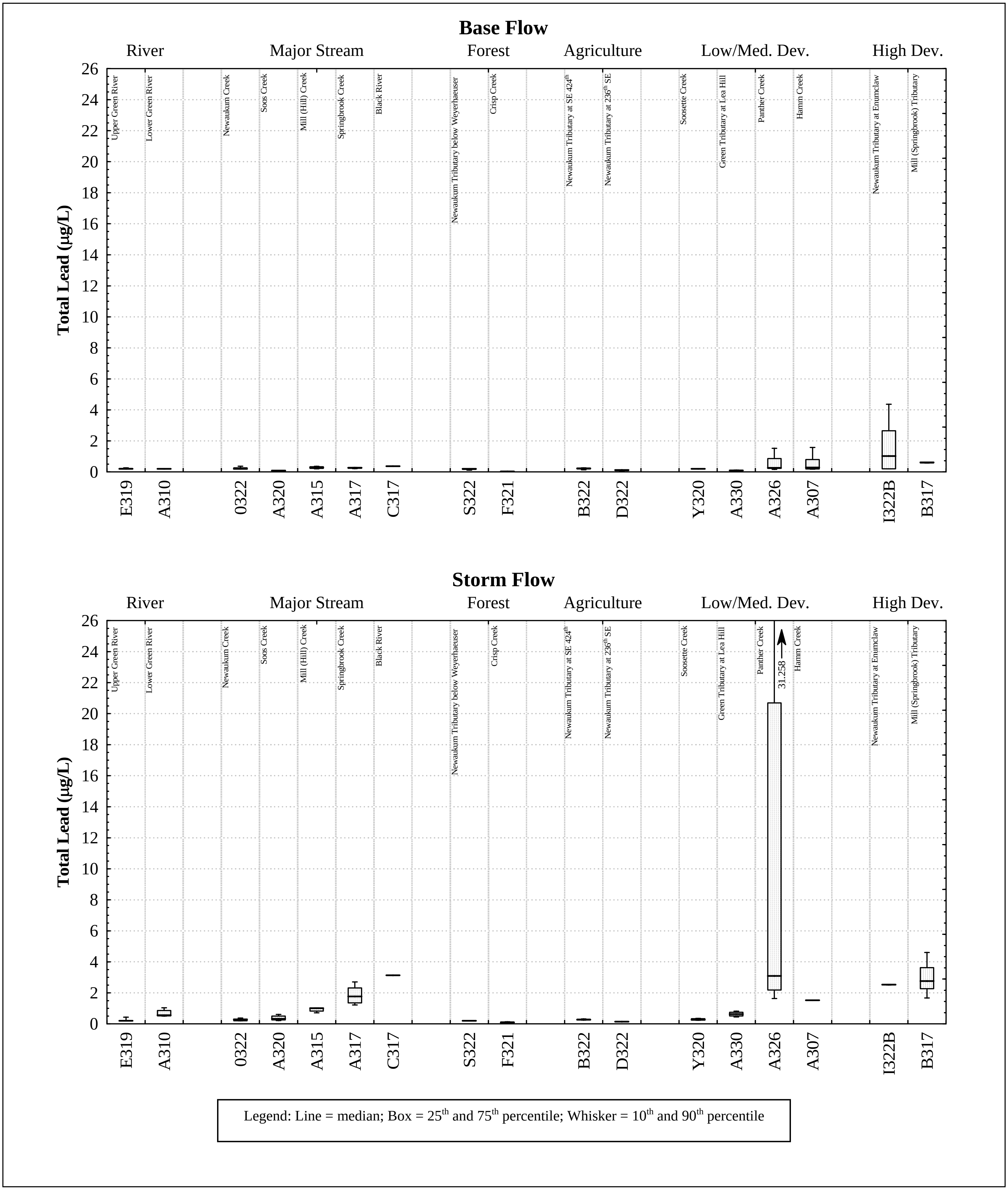


Figure 38. Total lead concentrations at sites in the Green-Duwamish watershed in 2003.

were no significant differences in total lead concentrations during base flow. During storm flow (Table P15, Appendix P), dissolved lead concentrations were significantly higher ($p = 0.0055$) in Springbrook Creek (A317) relative to Soos Creek (A320), and total lead concentrations were significantly higher ($p = 0.0109$) in Springbrook Creek (A317) relative to Newaukum Creek (0322).

The tributary sites exhibited lead concentrations that were similar to those for the major stream sites with the exception of one extremely high total lead concentration (38.3 µg/L) during storm flow at Panther Creek (A326).

5.3.5.7 Mercury

Summary statistics for dissolved mercury during base and storm flow are presented in Figure 39 (and Table F13, Appendix F). Summary statistics for total mercury during base and storm flow are presented in Figure 40 (and Table F14, Appendix F). Washington State has established an acute criterion of 2.1 µg/L for dissolved mercury and a chronic criterion of 0.012 µg/L for total mercury (WAC 173-201A) (see Table 14). The acute criterion for total mercury was never exceeded during storm flow at any station. The chronic criterion for dissolved mercury was exceeded during base flow in one sample from Hamm Creek (A307) and one sample from Mill (Springbrook) tributary (B317).

Dissolved mercury concentrations ranged from less than 0.0002 to 0.0074 µg/L during base flow, and ranged from 0.0011 to 0.0075 µg/L during storm flow. Total mercury concentrations ranged from 0.0004 to 0.0512 µg/L during base flow, and ranged from 0.0014 to 0.204 µg/L during storm flow. The median dissolved mercury concentration for all sites combined was the same during both base flow and storm flow (at the detection limit of 0.0050 µg/L), and the median total mercury concentration was slightly higher during storm flow (0.0070 µg/L) than base flow (0.0050 µg/L).

Spatial pattern analysis results for the Green River show there were no significant differences in dissolved or total mercury concentrations between the upper and lower sites during either base flow or storm flow (Table P13, Appendix P). Dissolved and total mercury concentrations were significantly different among some major stream sites (Tables P14 and P15, Appendix P), but those observed differences were primarily due to varying detection limits (ranging from 0.0002 to 0.0050 µg/L) for the analyzed samples.

The tributary sites exhibited mercury concentrations that were similar to those for the major stream sites with the exception that median dissolved and total mercury concentrations were highest during storm flow in Hamm Creek (A307).

5.3.5.8 Nickel

Summary statistics for dissolved nickel during base and storm flow are presented in Figure 41 (and Table F15, Appendix F). Summary statistics for total nickel during base and storm flow are presented in Figure 42 (and Table F16, Appendix F). Washington State surface water quality

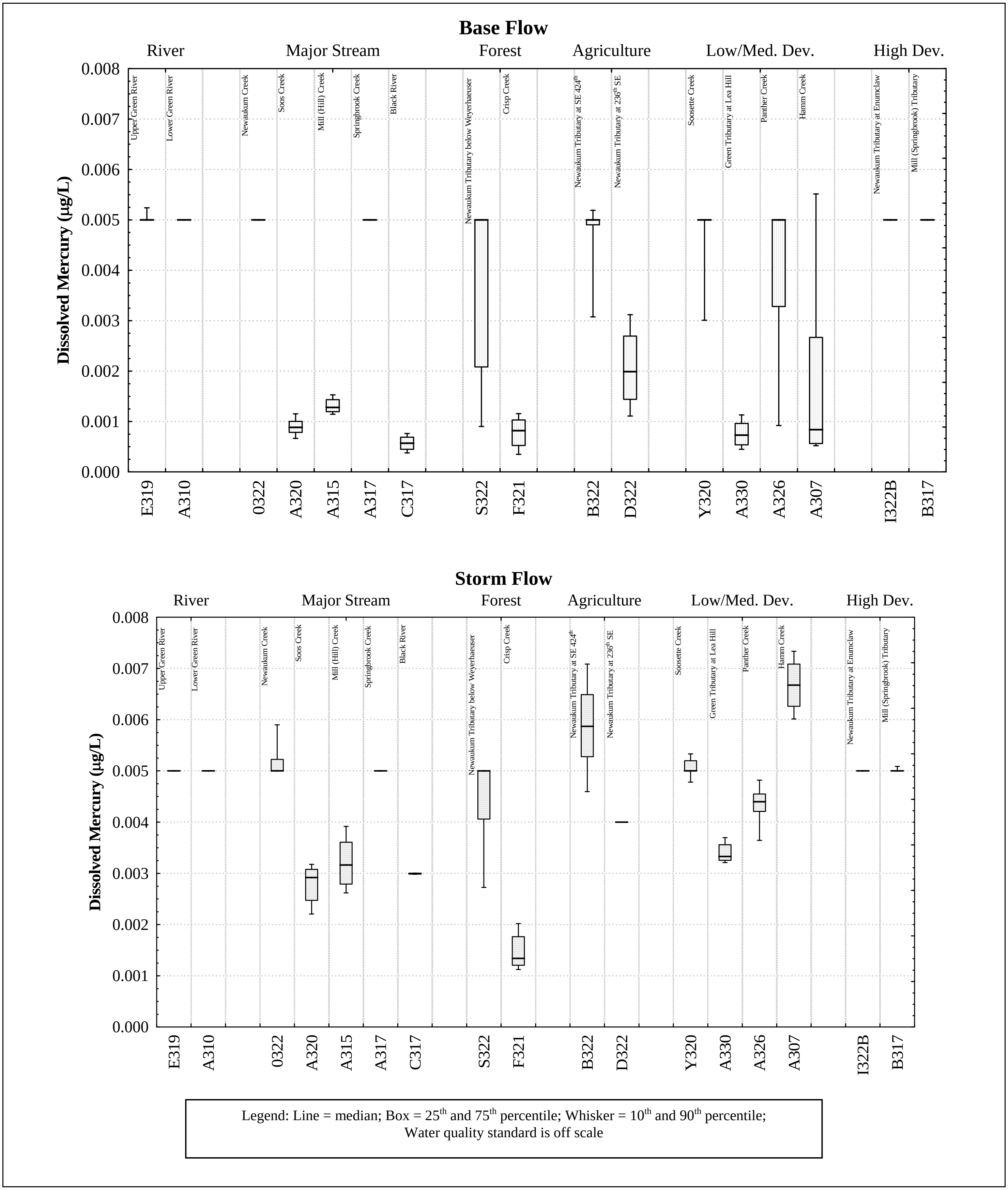


Figure 39. Dissolved mercury concentrations at sites in the Green-Duwamish watershed in 2003.

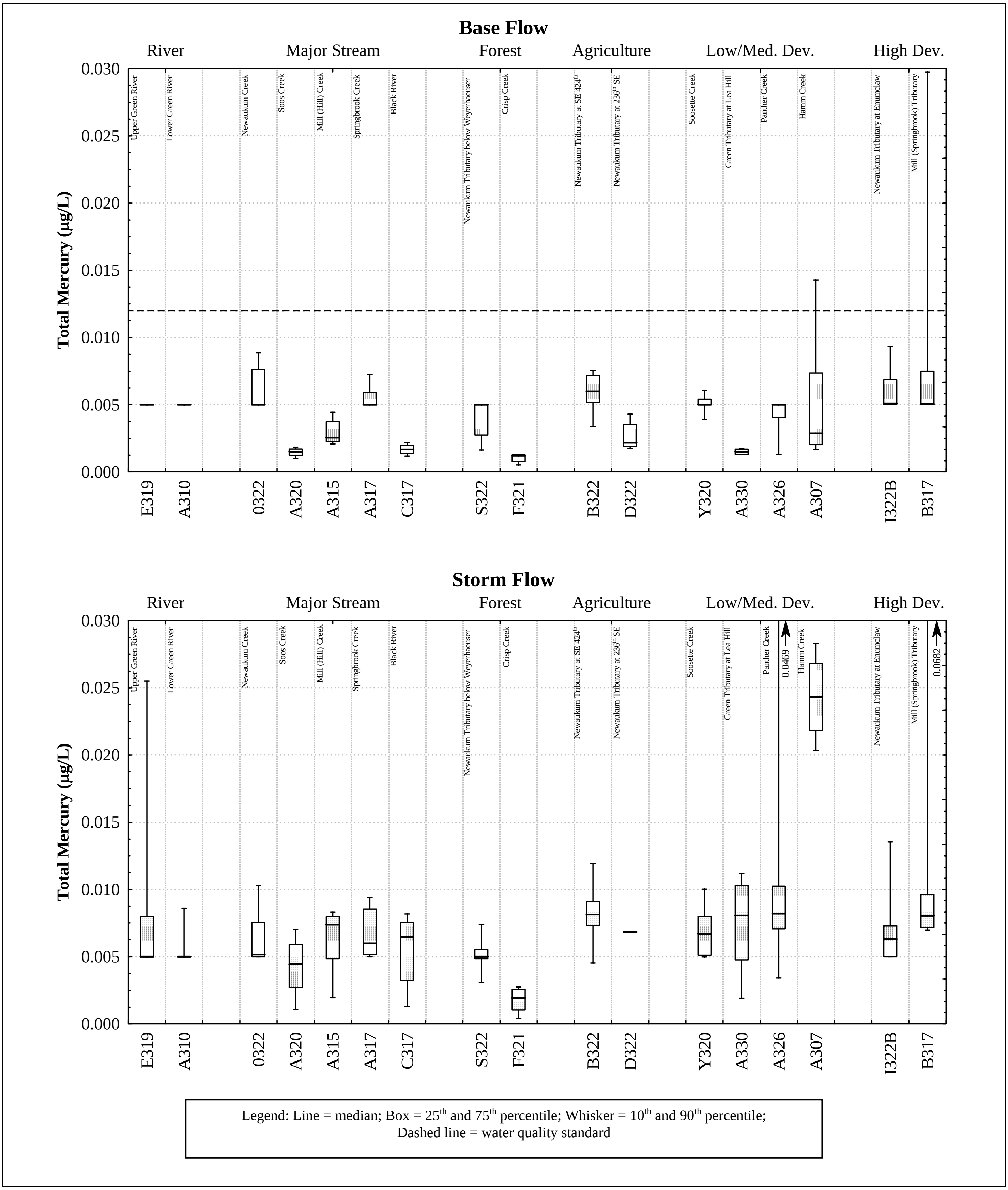


Figure 40. Total mercury concentrations at sites in the Green-Duwamish watershed in 2003.

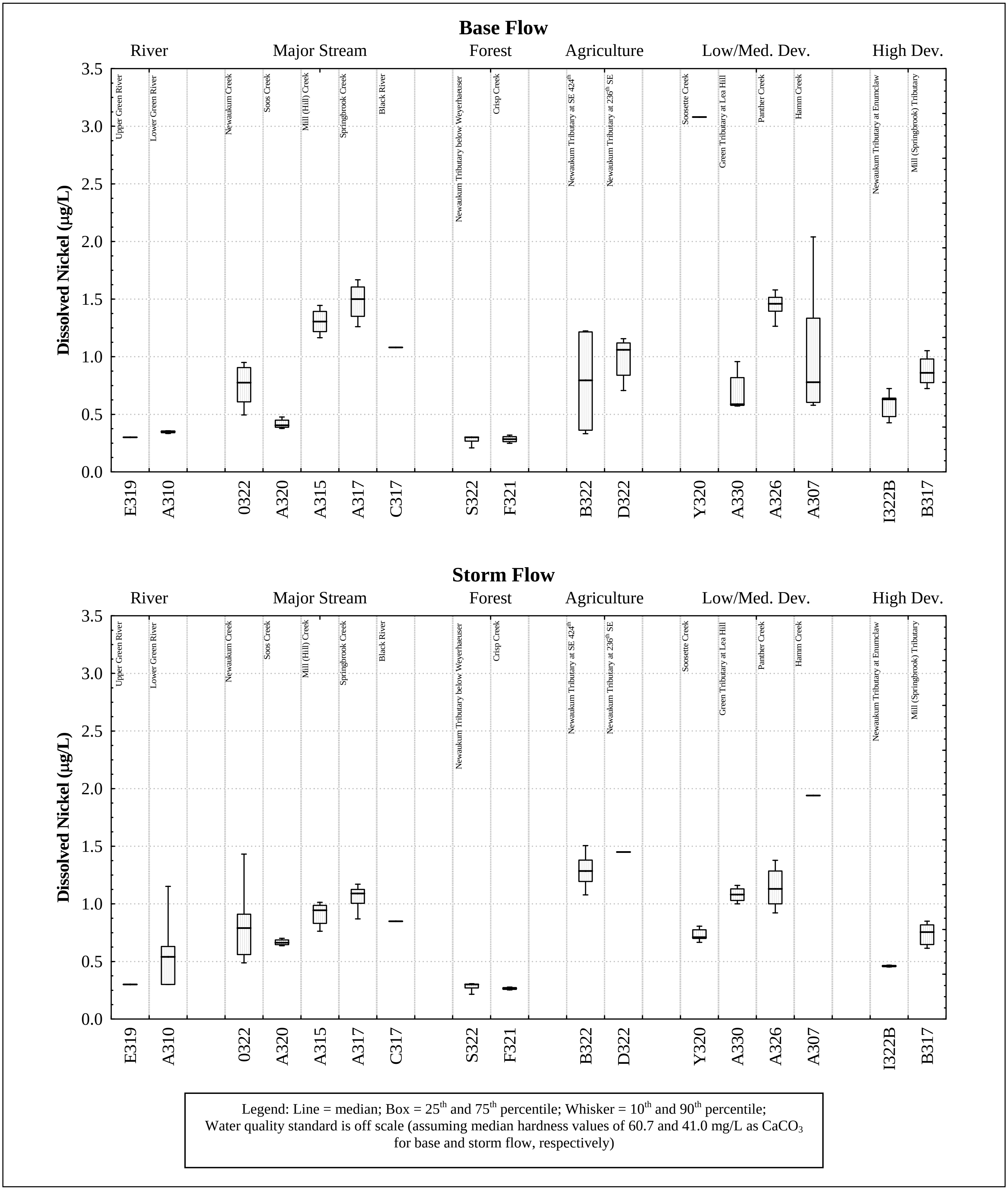


Figure 41. Dissolved nickel concentrations at sites in the Green-Duwamish watershed in 2003.

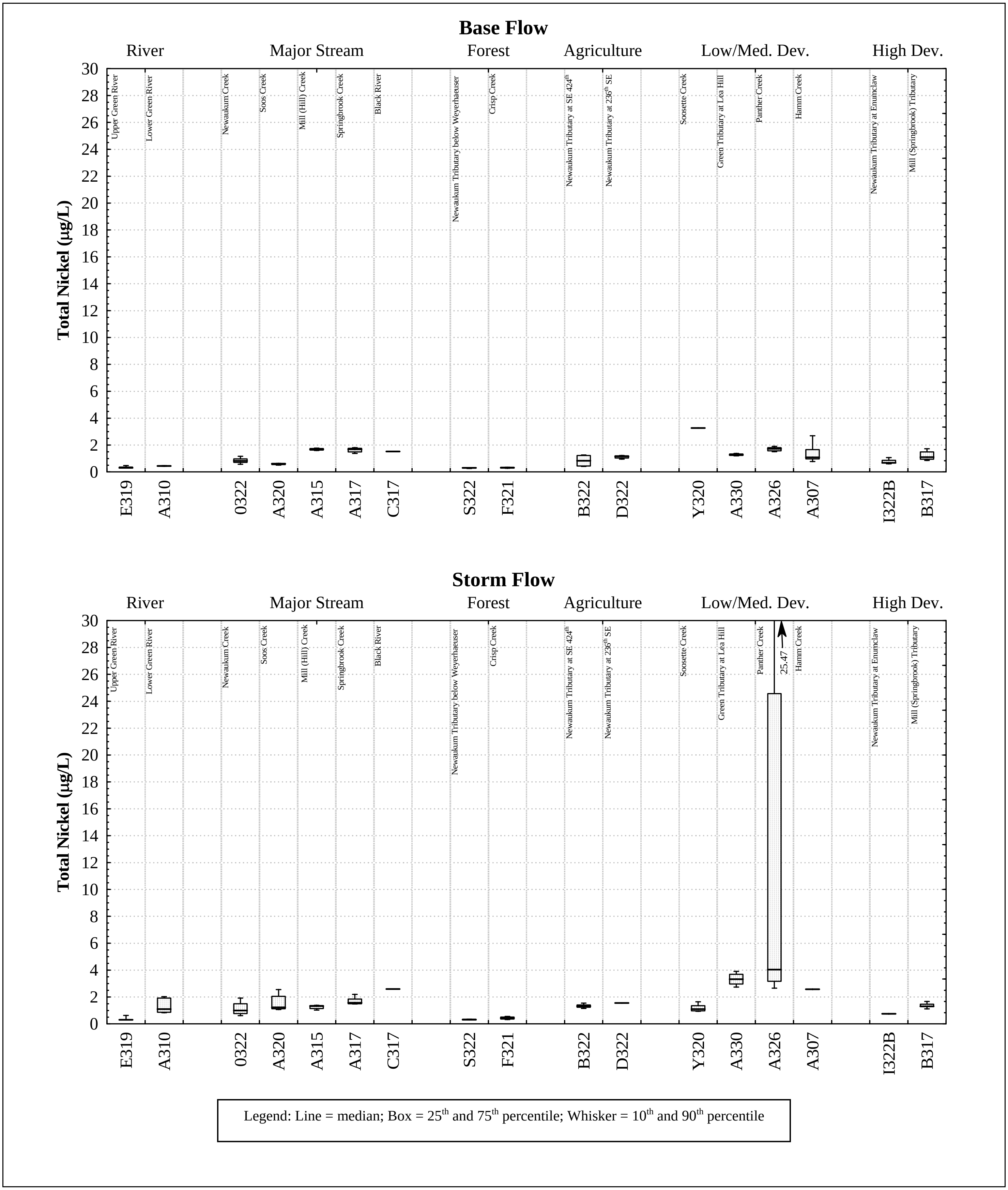


Figure 42. Total nickel concentrations at sites in the Green-Duwamish watershed in 2003.

standards (WAC 173-201A) include acute and chronic criteria for dissolved nickel that vary with hardness (Table 14). None of the sample values exceeded the state chronic criterion during base flow or the acute criterion during storm flow.

Dissolved nickel concentrations ranged from less than 0.17 to 3.08 µg/L during base flow, and ranged from 0.18 to 1.94 µg/L during storm flow. Total nickel concentrations ranged from 0.23 to 3.37 µg/L during base flow, and ranged from 0.29 to 45.1 µg/L during storm flow. Median dissolved nickel concentrations for all sites combined were similar during storm flow (0.72 µg/L) and base flow (0.66 µg/L). Median total nickel concentrations for all sites combined were also similar during storm flow (1.30 µg/L) and during base flow (1.00 µg/L).

Based on results of the spatial pattern analysis for the Green River, there was no significant difference in dissolved nickel concentrations between upstream and downstream stations during either base flow or storm flow (Table P13, Appendix P). Total nickel concentrations significantly increased downstream during storm flow ($p = 0.0159$), but not during base flow. The median total nickel concentration increased downstream from 0.30 to 1.10 µg/L during storm flow. In 2001-2002, dissolved and total nickel concentrations increased significantly downstream during base flow, and total nickel concentrations increased significantly downstream during storm flow (Herrera 2004).

Spatial pattern analysis for the major streams show that base flow dissolved nickel concentrations were significantly higher ($p = 0.0238$) in Springbrook Creek (A317) relative to Soos Creek (A320) (Table P14, Appendix P), and base flow total nickel concentrations were significantly higher ($p = 0.0437$) in the Mill (Hill) Creek (A315) relative to Soos Creek (A320). During storm flow, there were no significant differences among the four streams analyzed for either dissolved or total nickel. (Only one storm flow sample was collected from Black River [C317].)

The tributary sites exhibited nickel concentrations that were similar to those for the major stream sites with the exception of an elevated dissolved nickel concentration in Soosette Creek (Y320) observed during base flow and in Hamm Creek (A307) during storm flow. Also, elevated total nickel concentrations were observed during storm flow in Green tributary at Lea Hill (A330) and in Panther Creek (A326).

5.3.5.9 Selenium

Summary statistics for dissolved selenium during base and storm flow are presented in Figure 43 (and Table F17, Appendix F). Summary statistics for total selenium during base and storm flow are presented in Figure 44 (and Table F18, Appendix F). Washington State surface water quality standards (WAC 173-201A) include an acute criterion of 20 µg/L and a chronic criterion of 5 µg/L for total selenium (Table 14) that were used for comparison to storm flow and base flow results, respectively. Total selenium concentrations (and detection limits) did not exceed the criteria at any site during either base flow or storm flow.

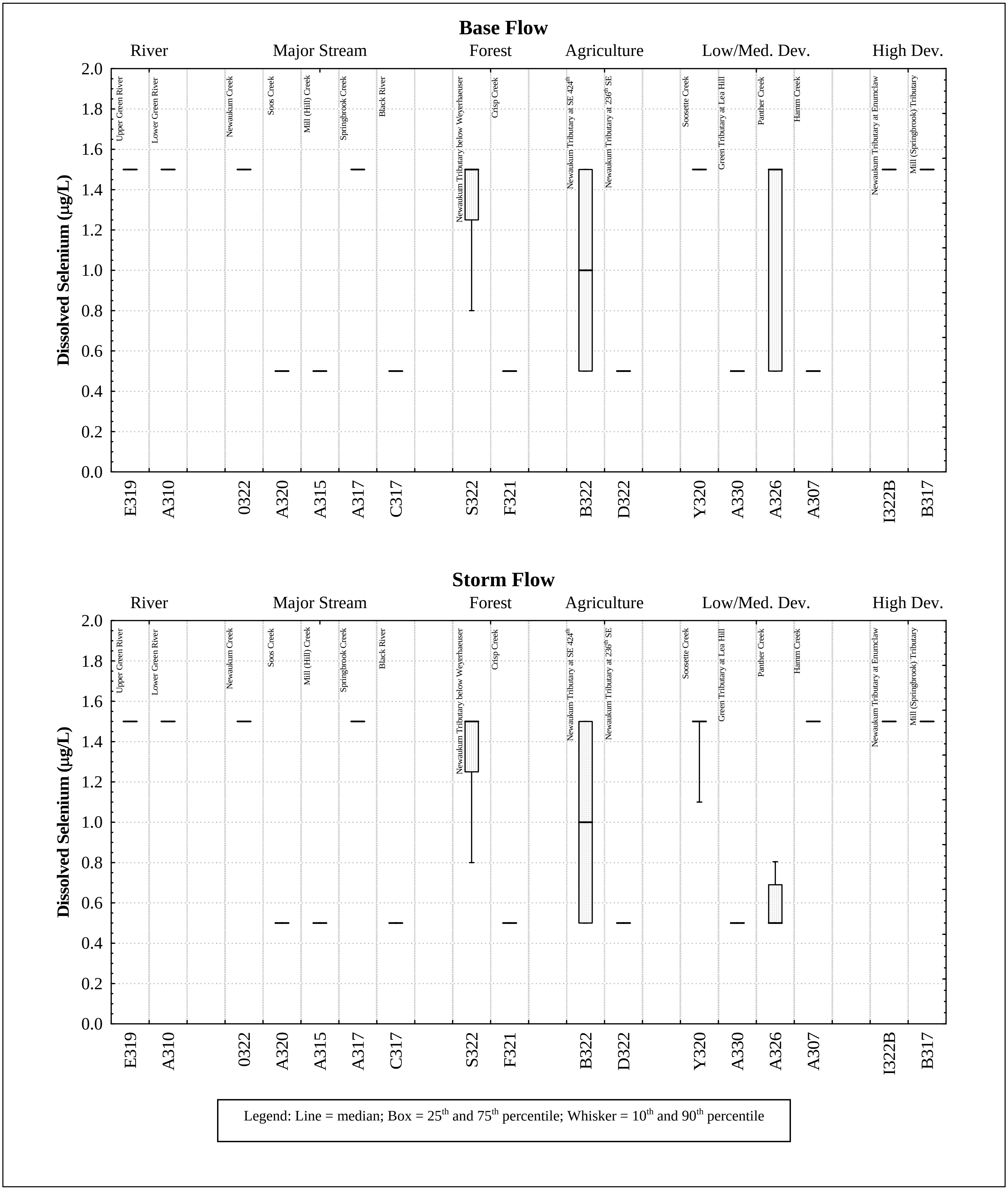


Figure 43. Dissolved selenium concentrations at sites in the Green-Duwamish watershed in 2003.

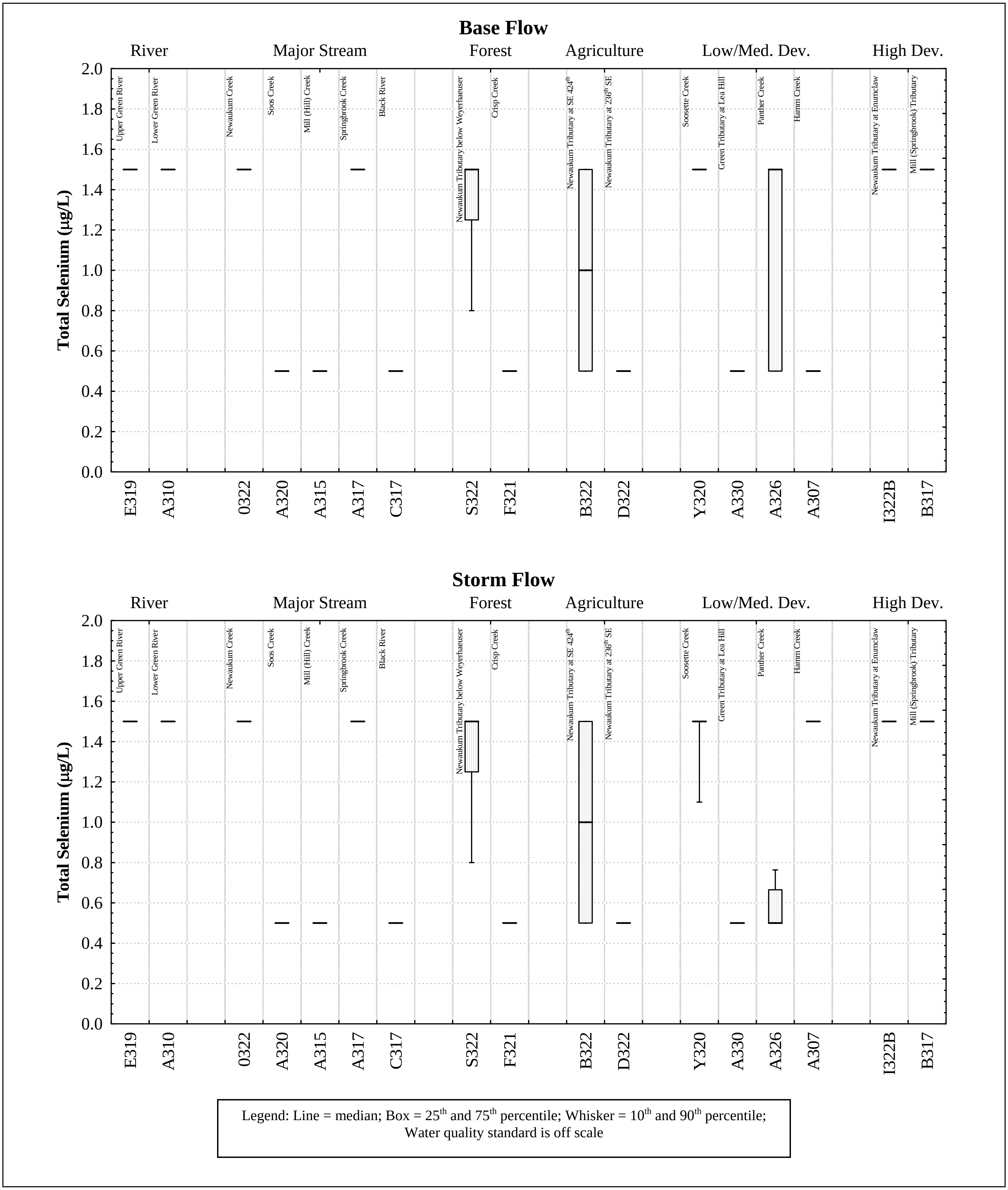


Figure 44. Total selenium concentrations at sites in the Green-Duwamish watershed in 2003.

Dissolved and total selenium were not detected in any of the base flow or storm flow samples with the exception that dissolved selenium was detected in one base flow sample (0.9 µg/L) and one storm flow sample (0.8 µg/L) collected from Panther Creek (A326). Method detection limits for dissolved and total selenium ranged from 0.5 to 1.5 µg/L. There were no significant differences in selenium concentrations (or detection limits) among the Green River sites (Table P13, Appendix P). Spatial pattern analysis was not performed for the major stream sites because of the lack of detected values.

5.3.5.10 Silver

Summary statistics for dissolved silver during base and storm flow are presented in Figure 45 (and Table F19, Appendix F). Summary statistics for total silver during base and storm flow are presented in Figure 46 (and Table F20, Appendix F). Washington State surface water quality standards (WAC 173-201A) include an acute criterion for dissolved silver that varies with hardness (Table 14).

Dissolved and total silver was not detected in any of the base flow and storm flow samples. Method detection limits for dissolved and total silver ranged from 0.025 to 0.200 µg/L. Undetected values for dissolved silver exceeded the acute criterion on five occasions at Upper Green River (E319) and on one occasion at Mill (Springbrook) tributary (B317) because the detection limit of 0.200 µg/L exceeds the acute criterion at low hardness values (i.e., less than 20 mg/L as $CaCO_3$). There were no significant differences in silver concentrations (or detection limits) among the Green River sites (Table P13, Appendix P). Spatial pattern analysis was not performed for the major stream sites because of the lack of detected values.

5.3.5.11 Zinc

Summary statistics for dissolved zinc during base and storm flow are presented in Figure 47 (and Table F21, Appendix F). Summary statistics for total zinc during base and storm flow are presented in Figure 48 (and Table F22, Appendix F). Washington State surface water quality standards (WAC 173-201A) include acute and chronic criteria for dissolved zinc that vary with hardness (see Table 14). The acute criterion was exceeded on one occasion during storm flow at Mill (Springbrook) tributary (29.6 µg/L dissolved zinc at site B317). The chronic criterion was never exceeded during base flow at any monitoring site.

Dissolved zinc concentrations ranged from 0.21 to 35.0 µg/L during base flow, and ranged from 0.29 to 31.0 µg/L during storm flow. Total zinc concentrations ranged from 0.34 to 37.40 µg/L during base flow, and ranged from 0.29 µg/L to 108.00 µg/L during storm flow. The median dissolved zinc concentration for all sites combined was substantially higher during storm flow (3.56 µg/L) than during base flow (1.66 µg/L).

Based on results of the spatial pattern analysis for the Green River sites, there were no significant differences in dissolved or total zinc concentrations between upstream and downstream during either base flow or storm flow in 2003 (Table P13, Appendix P). In 2001-2002, dissolved zinc concentrations increased significantly downstream during storm flow, and total zinc

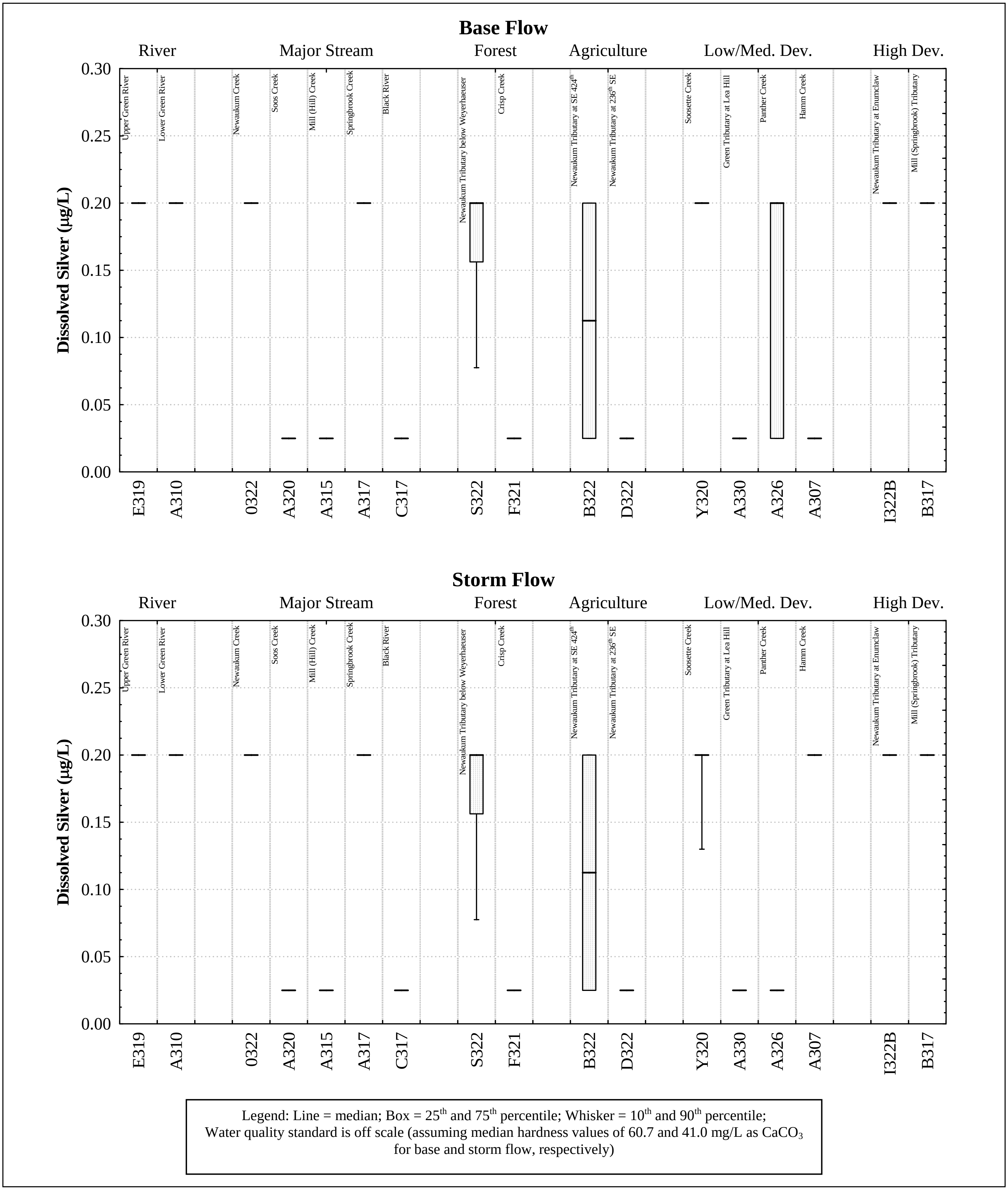


Figure 45. Dissolved silver concentrations at sites in the Green-Duwamish watershed in 2003.

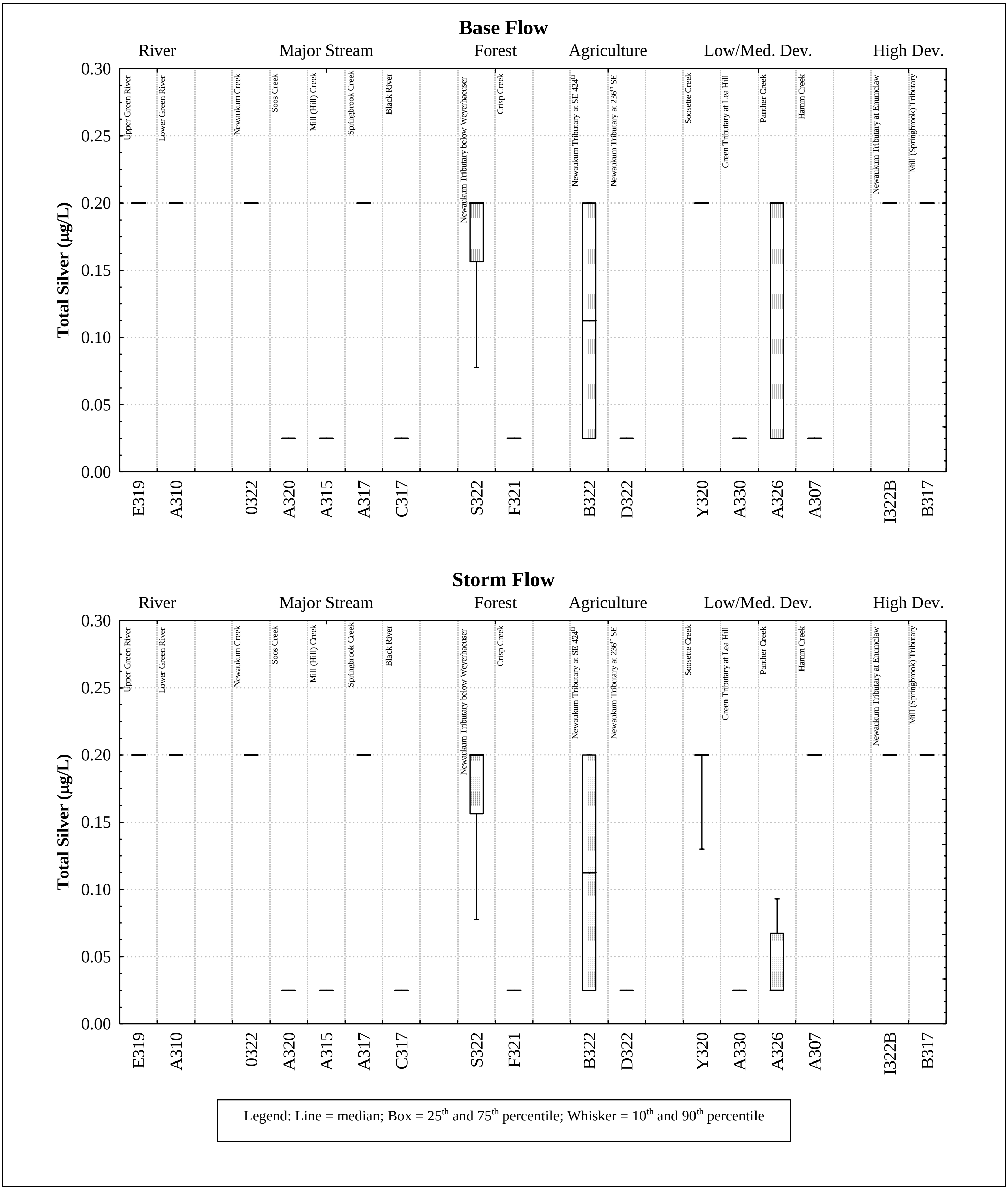
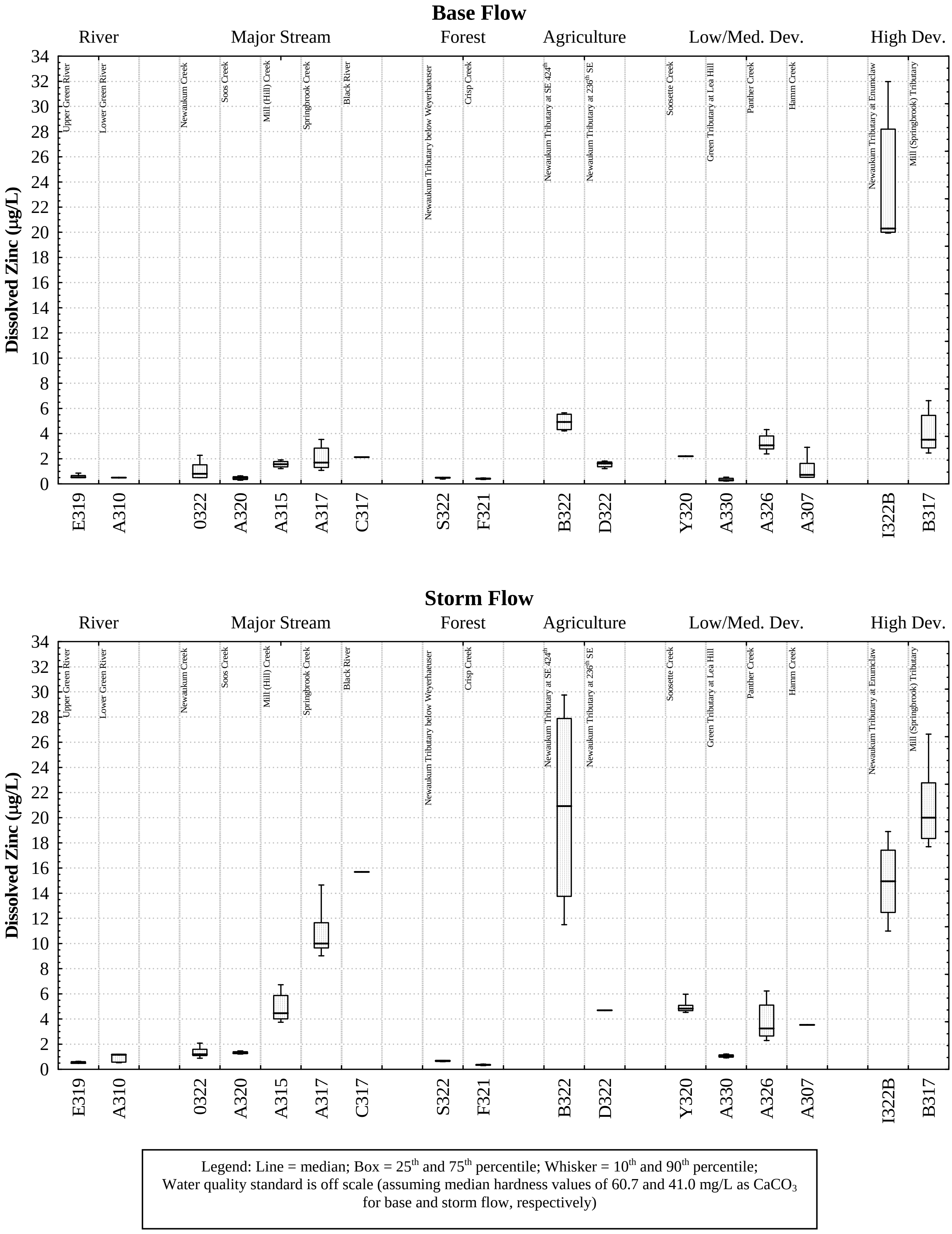


Figure 46. Total silver concentrations at sites in the Green-Duwamish watershed in 2003.



Legend: Line = median; Box = 25th and 75th percentile; Whisker = 10th and 90th percentile;
Water quality standard is off scale (assuming median hardness values of 60.7 and 41.0 mg/L as $CaCO_3$ for base and storm flow, respectively)

Figure 47. Dissolved zinc concentrations at sites in the Green-Duwamish watershed in 2003.

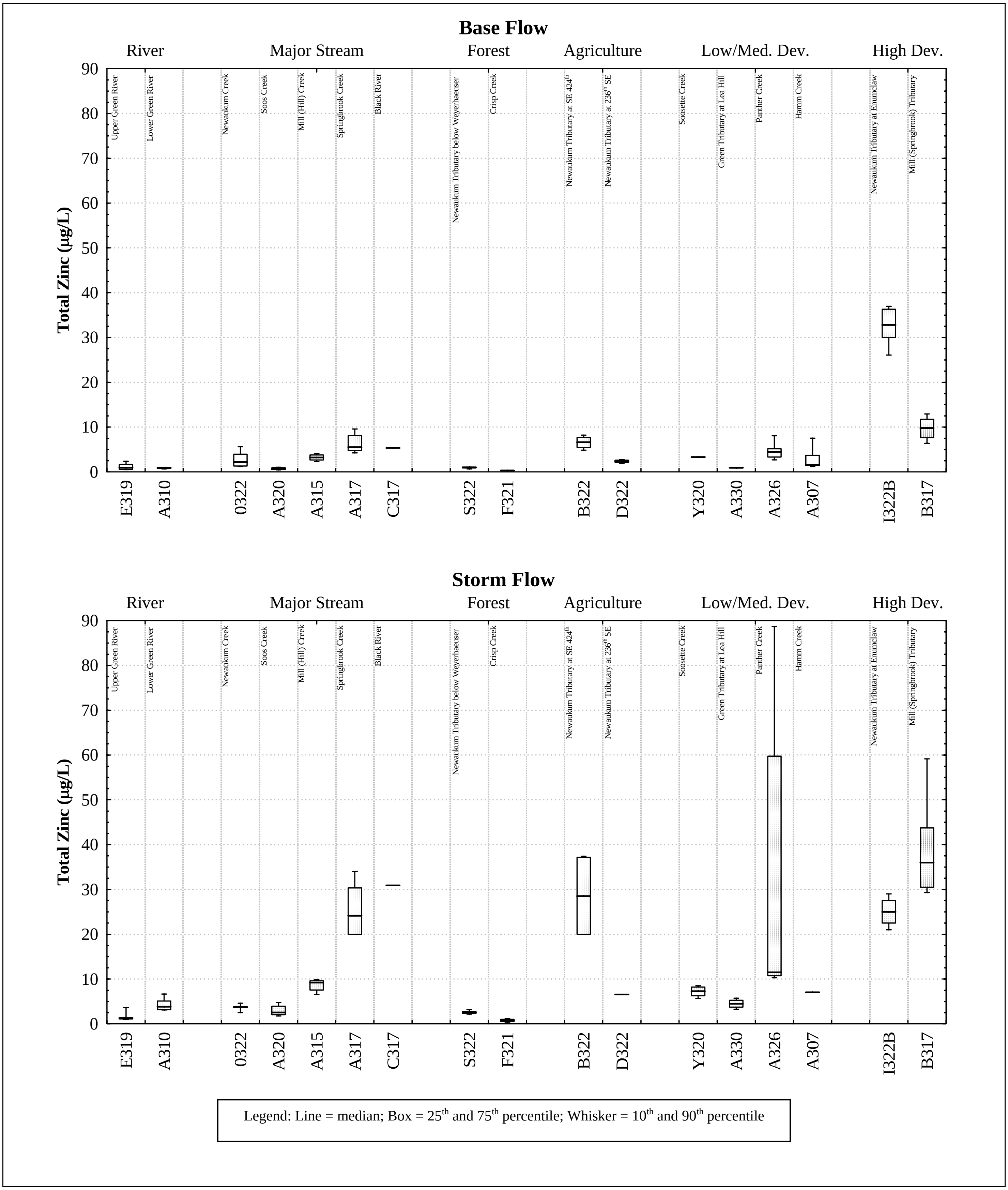


Figure 48. Total zinc concentrations at sites in the Green-Duwamish watershed in 2003.

concentrations increased significantly downstream during base flow and storm flow (Herrera 2004).

Results of the spatial pattern analysis for the major streams show that the median dissolved zinc concentration was significantly higher during storm flow ($p = 0.0088$) in Springbrook Creek (A317) relative to Newaukum Creek (0322) (Table P15, Appendix P), and there were no significant differences in dissolved zinc concentrations during base flow. Total zinc concentrations were significantly ($p = 0.0088$) higher during storm flow in Springbrook Creek (A317) relative to Soos Creek (A320) and Newaukum Creek (0322).

Median dissolved and total zinc concentrations were highest at Newaukum tributary at Enumclaw (I322B) during base flow, which was also observed in 2001-2002 (Herrera 2004). During storm flow, median dissolved zinc concentrations were highest at the Newaukum tributary at SE 424th (B322) and Mill (Springbrook) tributary (B317), and the median total zinc concentration was also highest in the Mill (Springbrook) tributary (B317).

5.3.6 Minerals

This section summarizes results for minerals based on the data collected in 2003 for the GDWQA. Summary statistics for these parameters are presented in Appendix G and results from associated statistical spatial pattern analyses are presented in Appendix P. Minerals analyzed for the GDWQA include:

- Calcium
- Iron
- Magnesium
- Manganese
- Potassium
- Sodium.

5.3.6.1 Calcium

Summary statistics for dissolved calcium during base and storm flow are presented in Figure 49 (and Table G1, Appendix G). Summary statistics for total calcium during base and storm flow are presented in Figure 50 (and Table G2, Appendix G). Washington State does not have surface water quality criteria for total or dissolved calcium (WAC 173-201A).

For all streams, dissolved calcium concentrations ranged from 3.88 to 28.0 mg/L during base flow, and from 2.23 to 24.7 mg/L during storm flow. Total calcium concentrations ranged from 4.30 to 28.8 mg/L during base flow, and ranged from 4.26 to 24.6 mg/L during storm flow. The median total calcium concentration for all sites was higher during base flow (14.1 mg/L) than storm flow (9.06 mg/L).

Spatial pattern analysis results for the Green River show that dissolved calcium concentrations increased significantly downstream from the upper to lower site during base flow ($p = 0.0061$)

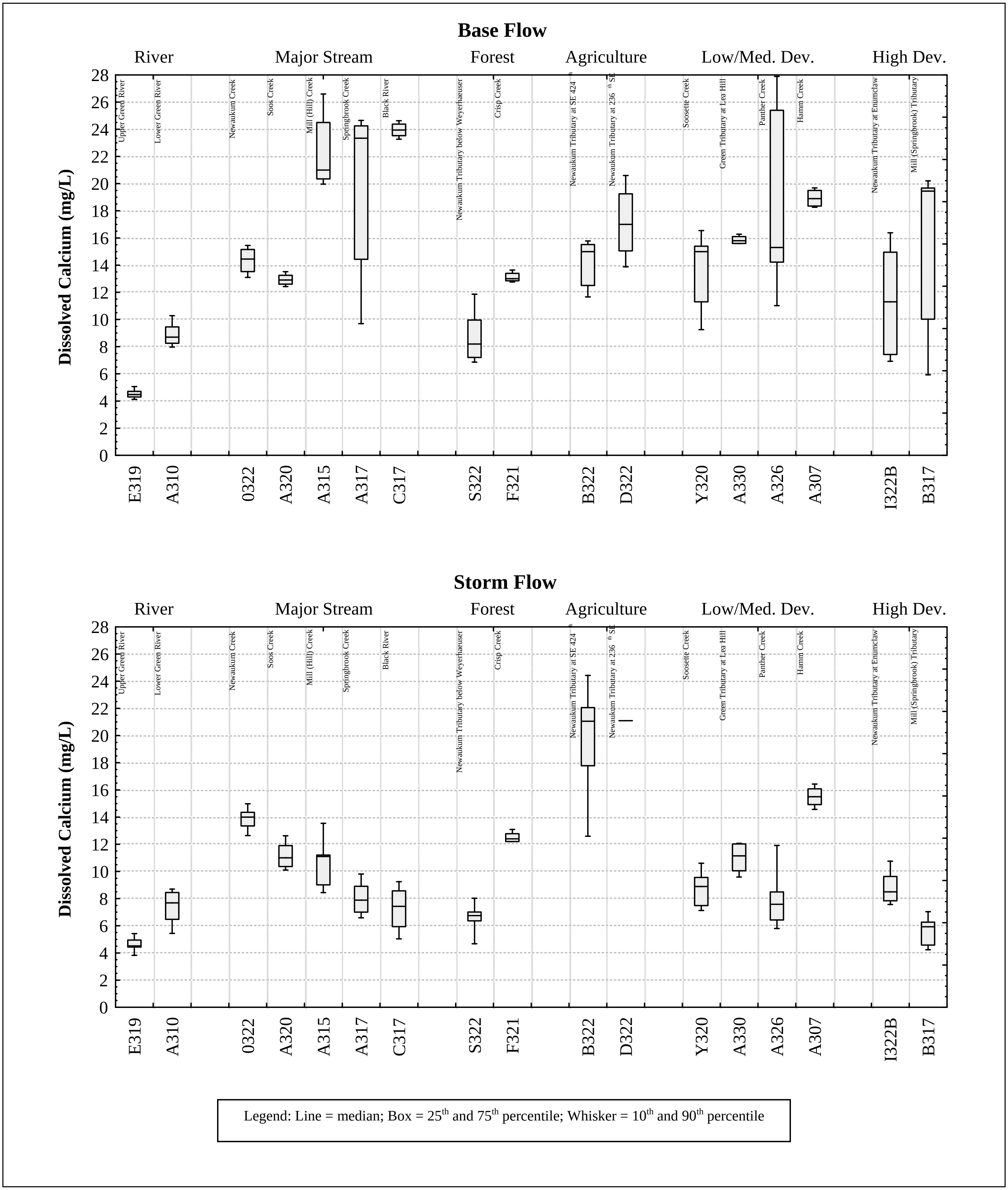


Figure 49. Dissolved calcium concentrations at sites in the Green-Duwamish watershed in 2003.

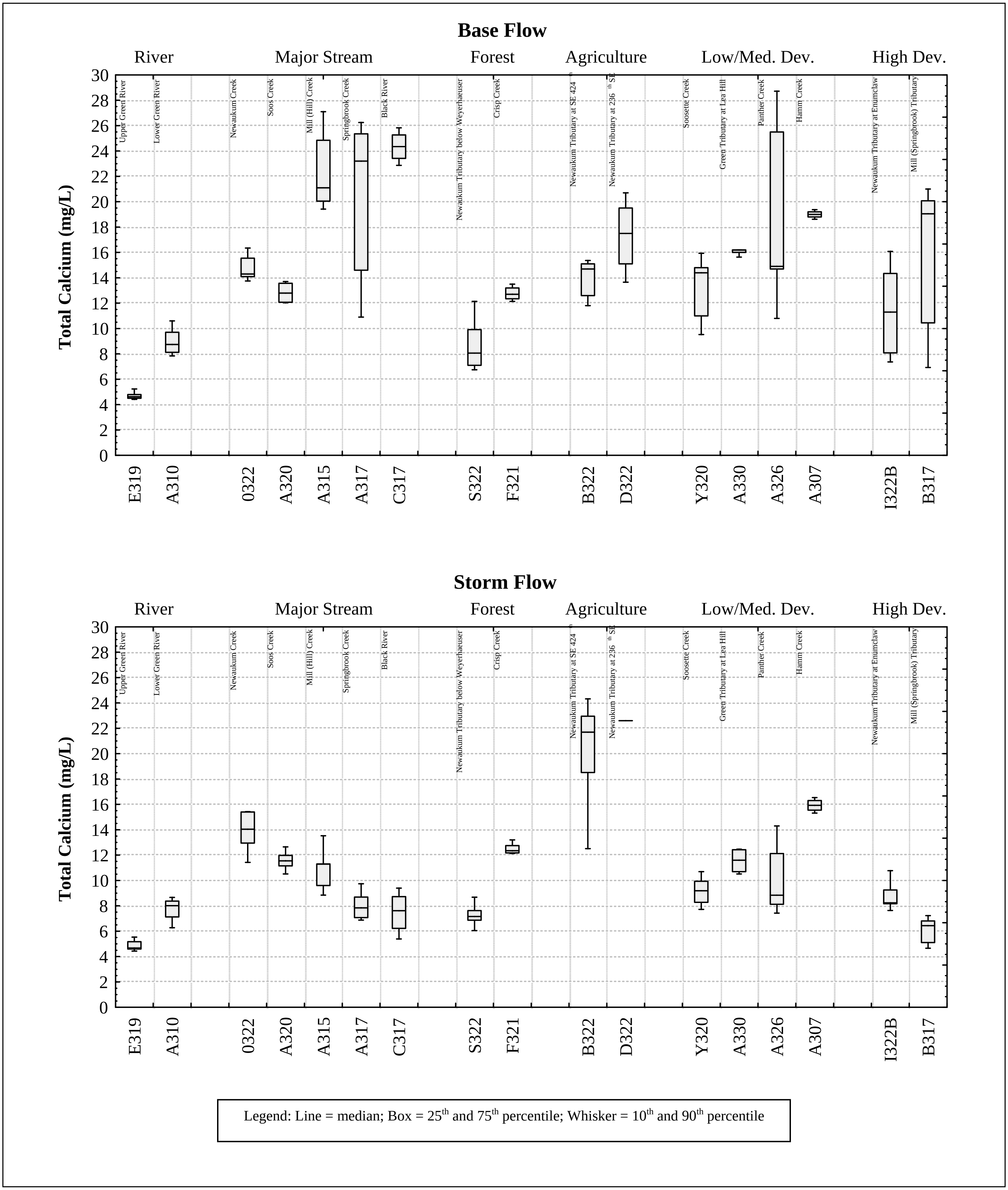


Figure 50. Total calcium concentrations at sites in the Green-Duwamish watershed in 2003.

and storm flow (p = 0.0221) (Table P16, Appendix P). Total calcium concentrations also increased significantly downstream in the Green River during base flow (p = 0.0040) and storm flow (p = 0.0023). The median total calcium concentration increased downstream from 4.63 to 8.75 mg/L during base flow, and from 4.68 to 8.01 mg/L during storm flow.

Based on the spatial pattern analysis results for the major stream sites, dissolved calcium concentrations were not significantly different during base flow but were significantly higher (p = 0.0025) during storm flow in Newaukum Creek (0322) relative to Springbrook Creek (A317) and the Black River (C317) (Tables P17 and P18, Appendix P). Total calcium concentrations were not significantly different during base flow, but were significantly higher (p = 0.0024) in Newaukum Creek (0322) relative to Springbrook Creek (A317) and the Black River (C317) (Tables P17 and P18). In 2001-2002, significant differences were observed among the major stream sites for dissolved and total calcium only during base flow.

The tributary sites exhibited calcium concentrations that were similar to those for the major stream sites and those measured in 2001-2002.

5.3.6.2 Iron

Summary statistics for dissolved iron during base and storm flow are presented in Figure 51 (and Table G3, Appendix G). Summary statistics for total iron during base and storm flow are presented in Figure 52 (and Table G4, Appendix G). Washington State does not have surface water quality criteria for dissolved or total iron (WAC 173-201A). However, the EPA (2002a) has established a chronic criterion of 1.0 mg/L for iron.

For all streams, dissolved iron concentrations ranged from less than 0.05 to 1.30 mg/L during base flow, and from 0.03 to 0.43 mg/L during storm flow. Total iron concentrations ranged from 0.05 to 6.23 mg/L during base flow, and from 0.05 to 24.80 mg/L during storm flow. The median total iron concentration for all sites was higher during storm flow (0.88 mg/L) than base flow (0.31 mg/L).

Dissolved iron concentrations exceeded the chronic criterion on one occasion during base flow at Mill (Springbrook) tributary (B317). Total iron concentrations exceeded the chronic criterion in at least one sample collected at seven sites, and in all base flow samples collected at Mill (Hill) Creek (A315), Springbrook Creek (A317), and Black River (C317). In 2001-2003, total iron concentrations exceeded the chronic criterion in at least one sample at eight sites, Generally, the criterion were exceeded at the same sites in both years The median total iron concentration for all sites was higher during storm flow (0.88 mg/L) than during base flow (0.31 mg/L).

Based on results of the spatial pattern analysis for the Green River, dissolved iron concentrations increased significantly downstream during base flow (p = 0.0061) and storm flow (p = 0.0023) (Table P16, Appendix P). Median dissolved iron concentrations increased downstream from 0.05 to 0.16 mg/L during base flow and increased from 0.05 to 0.11 mg/L during storm flow. Total iron concentrations significantly increased downstream during base flow (p = 0.0485), but not during storm flow. The median total iron concentration increased downstream from 0.14 to

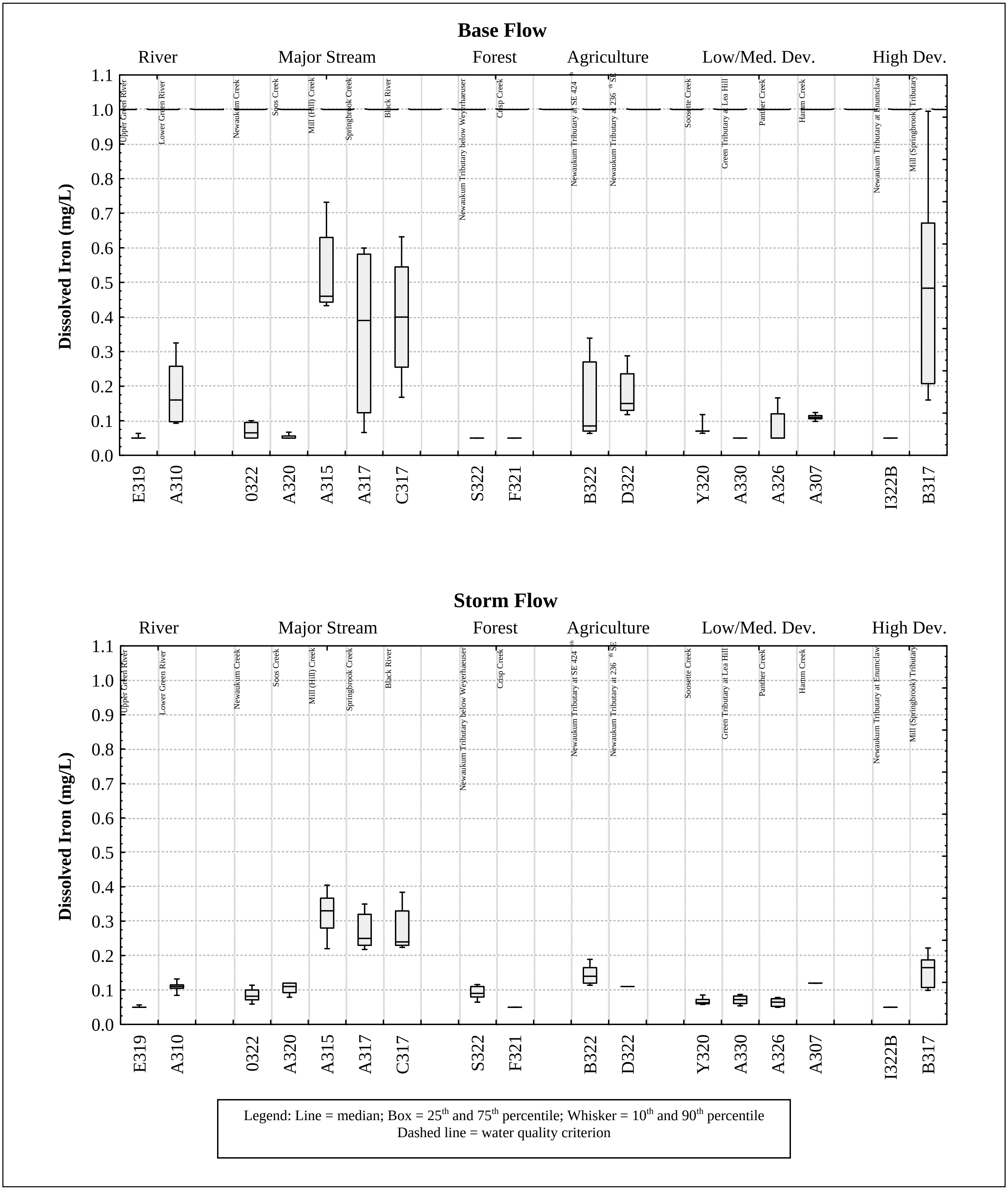


Figure 51. Dissolved iron concentrations at sites in the Green-Duwamish watershed in 2003.

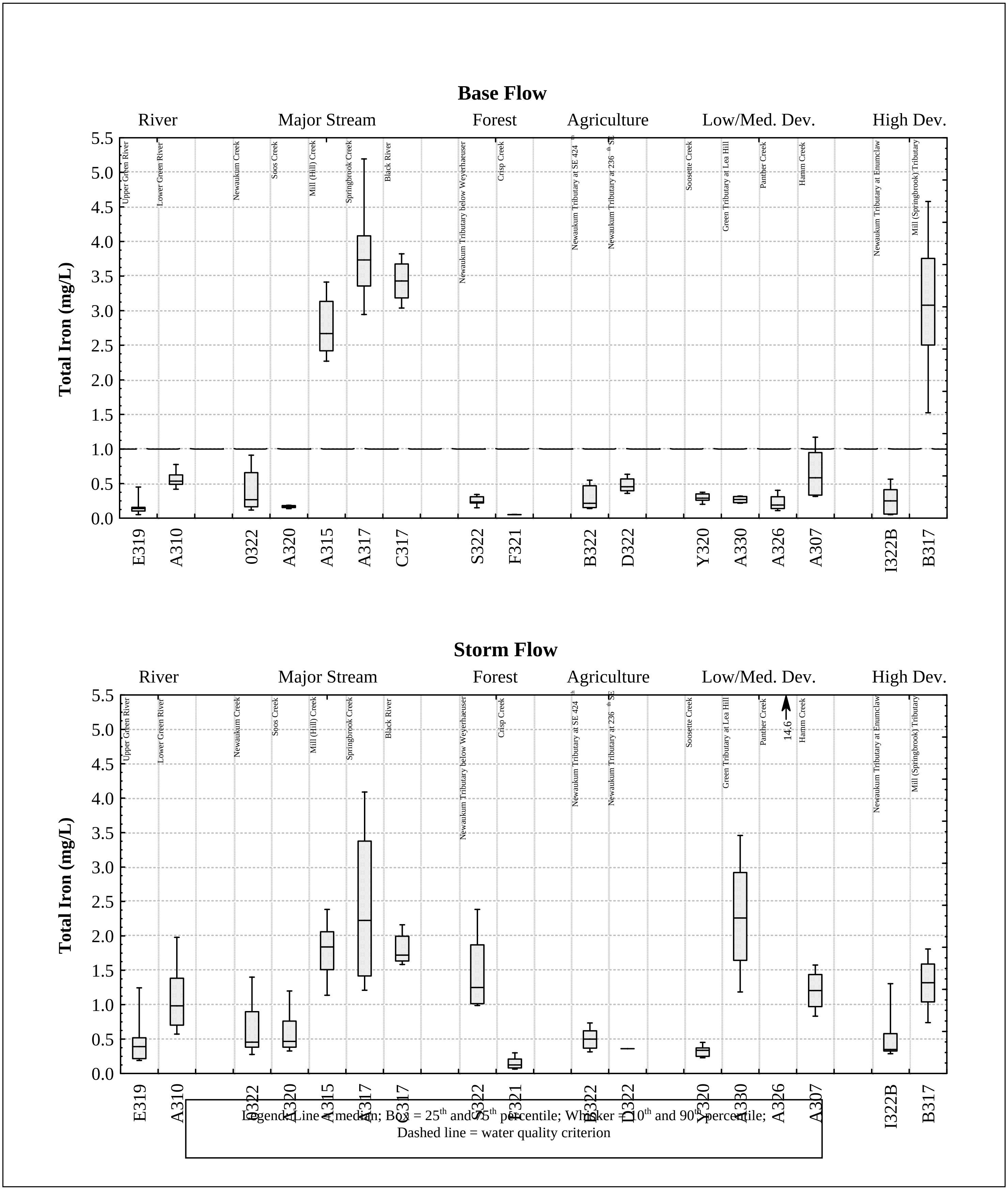


Figure 52. Total iron concentrations at sites in the Green-Duwamish watershed in 2003.

0.54 mg/L during base flow. Similar patterns for the spatial pattern analysis of dissolved and total iron concentrations in the Green River were observed in 2001-2002 (Herrera 2004).

Among the major streams, results of the spatial pattern analysis show that dissolved iron concentrations were significantly higher ($p = 0.0104$) during base flow in Mill Creek (A315) relative to Soos Creek (A320), and that dissolved iron concentrations were significantly higher ($p = 0.0014$) during storm flow in Mill Creek (A315) relative to Newaukum Creek (0322) (Tables P17 and P18, Appendix P). Total iron concentrations were significantly higher ($p = 0.0031$) during base flow in Springbrook Creek (A317) and the Black River (C317) relative to Soos Creek (A320) and Newaukum Creek (0322), and total iron concentrations were significantly higher ($p = 0.0091$) during storm flow in Springbrook Creek (A317) relative to Soos Creek (A320) and Newaukum Creek (0322) (Tables P17 and P18, Appendix P).

The tributary sites exhibited a wide range of iron concentrations that were similar to those observed in 2001-2002 (Herrera 2004). Among the tributary sites, the highest iron concentrations were observed at Mill (Springbrook) tributary (B317) where the median base flow concentration exceeded the median storm flow concentration for both dissolved and total iron. High median concentrations of total iron (exceeding 1.0 mg/L) were also observed during storm flow at the Green tributary at Lea Hill (A330), Panther Creek (A326), and Hamm Creek (A307).

5.3.6.3 Magnesium

Summary statistics for dissolved magnesium during base and storm flow are presented in Figure 53 (and Table G5, Appendix G). Summary statistics for total magnesium during base and storm flow are presented in Figure 54 (and Table G6, Appendix G). Washington State has not established surface water quality criteria for dissolved or total magnesium (WAC 173-201A).

For all monitoring sites, dissolved magnesium concentrations ranged from 0.68 to 16.1 mg/L during base flow, and from 0.52 to 11.7 mg/L during storm flow. Total magnesium concentrations ranged from 0.69 to 16.1 mg/L during base flow, and from 0.83 to 11.6 mg/L during storm flow. Dissolved and total magnesium concentrations were similar in each sample because nearly all of the magnesium present is in the dissolved state for all sites and flow conditions. The median total magnesium concentration for all sites was higher during base flow (4.64 mg/L) than storm flow (3.12 mg/L).

Based on results of the spatial pattern analysis for the Green River, dissolved magnesium concentrations were significantly higher downstream during base flow ($p = 0.0061$) and storm flow ($p = 0.0012$) (Table P16, Appendix P). The median dissolved magnesium concentration increased downstream from 0.75 to 2.73 mg/L during base flow, and from 0.80 to 2.26 mg/L during storm flow. Total magnesium concentrations were also significantly higher downstream during base flow ($p = 0.0040$) and storm flow ($p = 0.0012$). Median total magnesium concentrations increased downstream from 0.81 to 2.79 mg/L during base flow, and from 0.91 to 2.42 mg/L during storm flow. Similar patterns for dissolved and total magnesium concentrations in the Green River were observed in 2001-2002 (Herrera 2004).

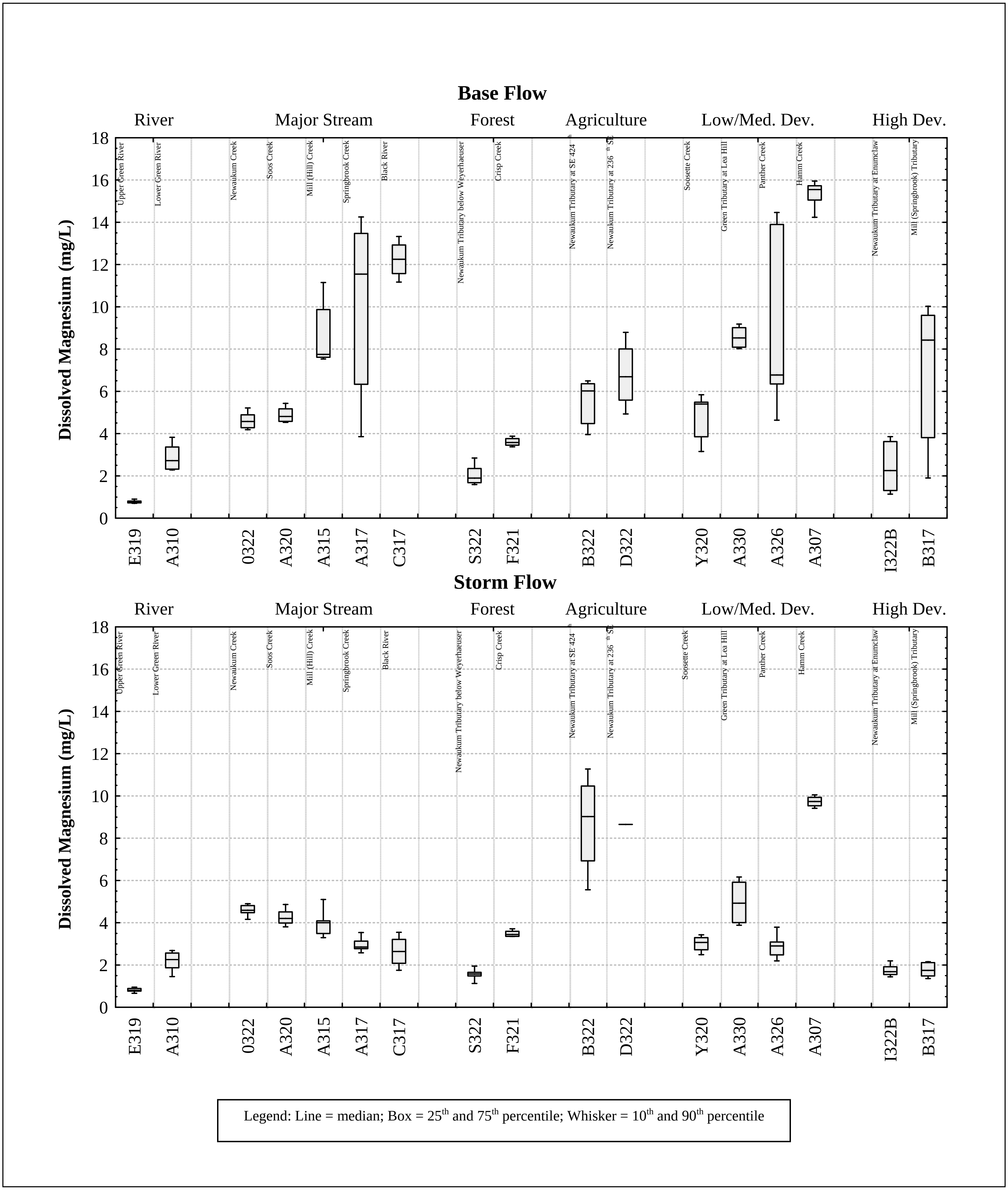


Figure 53. Dissolved magnesium concentrations at sites in the Green-Duwamish watershed in 2003.

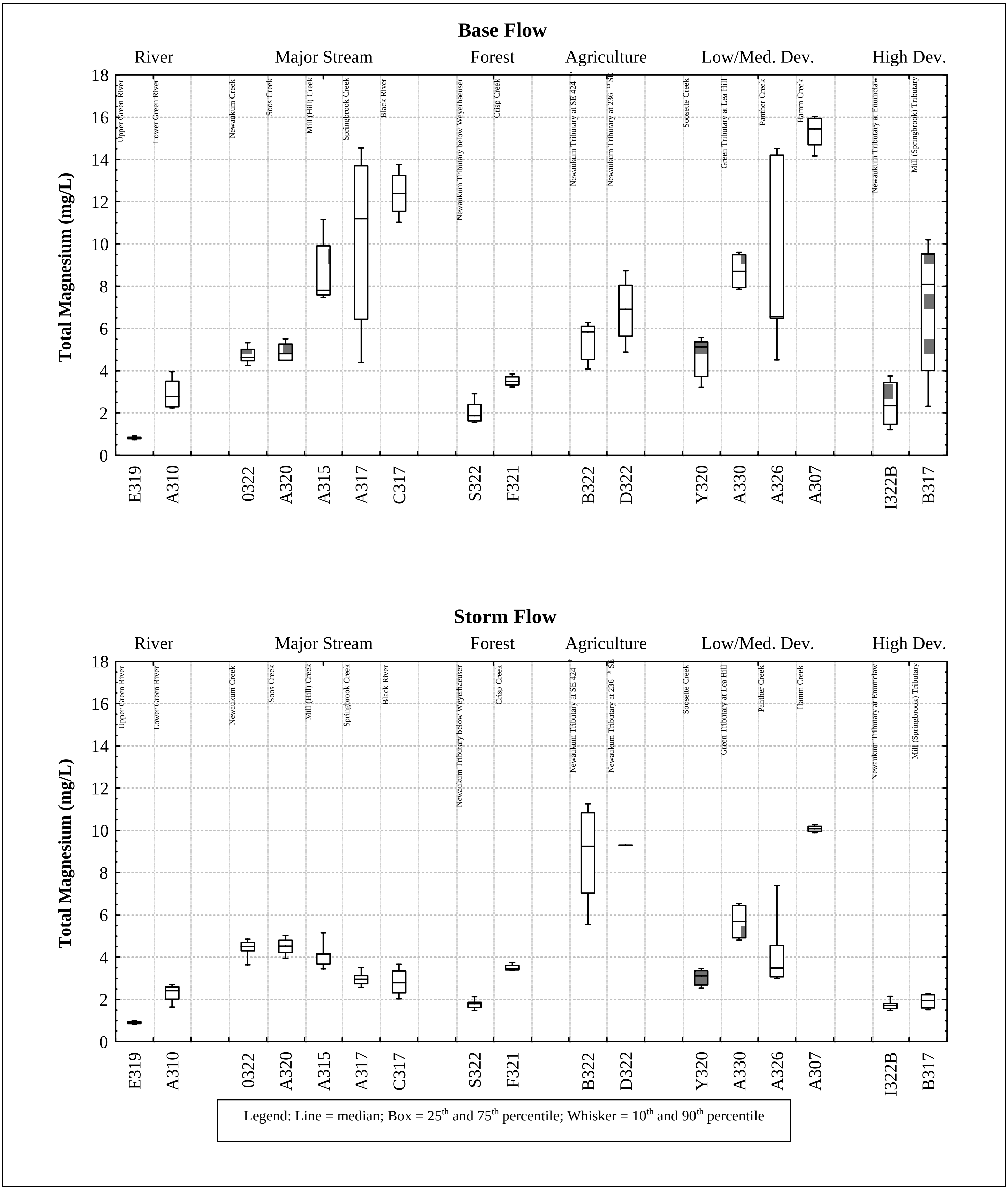


Figure 54. Total magnesium concentrations at sites in the Green-Duwamish watershed in 2003.

Spatial pattern analysis results for the major streams show no significant differences for dissolved and total magnesium concentrations during base flow conditions (Table P17, Appendix P). During storm flow, dissolved magnesium concentrations were significantly higher ($p = 0.0105$) at Newaukum Creek (0322) relative to the Black River (C317) and total magnesium concentrations were significantly higher ($p = 0.0092$) at Soos Creek (A320) relative to Springbrook Creek (A317) (Table P18, Appendix P). In contrast, significant differences were observed among stream sites during base flow but not storm flow in 2001-2002 (Herrera 2004).

The tributary sites exhibited magnesium concentrations that were similar to those for the major stream sites with the exception that median dissolved and total magnesium concentrations were highest at Hamm Creek (A307) during base and storm flow (which was also observed in 2001-2002). High magnesium concentrations were also detected during storm flow in the Newaukum tributaries representing agricultural land use (sites B322 and D322).

5.3.6.4 Manganese

Summary statistics for dissolved manganese during base and storm flow are presented in Figure 55 (and Table G7, Appendix G). Summary statistics for total manganese during base and storm flow are presented in Figure 56 (and Table G8, Appendix G). Washington State has not established surface water quality criteria for dissolved or total manganese (WAC 173-201A).

For all monitoring sites, dissolved manganese concentrations ranged from 0.0005 to 0.518 mg/L during base flow, and from 0.0008 to 0.054 mg/L during storm flow. Total manganese concentrations ranged from 0.0017 to 0.534 mg/L during base flow, and ranged from 0.0025 mg/L to 0.640 mg/L during storm flow. The median total manganese concentration for all sites was slightly higher during storm flow (0.044 mg/L) than base flow (0.040 mg/L). The median total manganese concentration for all sites was higher during base flow than storm flow in 2001-2002 (Herrera 2004).

Results of the spatial pattern analyses for the Green River showed no significant differences in dissolved or total manganese concentrations between the upper and lower sites during base flow and storm flow (Table P16, Appendix P). In 2001-2002, a significant increase in dissolved manganese concentrations was observed between the upper and lower Green River sites during storm flow.

Among the major stream sites, results of the spatial pattern analysis show that the dissolved manganese concentrations were significantly higher ($p = 0.0096$) during base flow in the Black River (C317) relative to Newaukum Creek (0322) and were significantly higher ($p = 0.0087$) during storm flow in the Black River (C317) and Mill Creek (A315) relative to Newaukum Creek (0322) (Tables P17 and P18, Appendix P). Total manganese concentrations were significantly higher ($p = 0.0113$) during base flow in Springbrook Creek (A317) relative to Soos Creek (A320). (The Black River [C317] site was not included the spatial pattern analysis of total manganese concentrations during base flow because only one sample was collected and two or more samples are required to perform a Kruskal-Wallis ANOVA analysis.) Total manganese

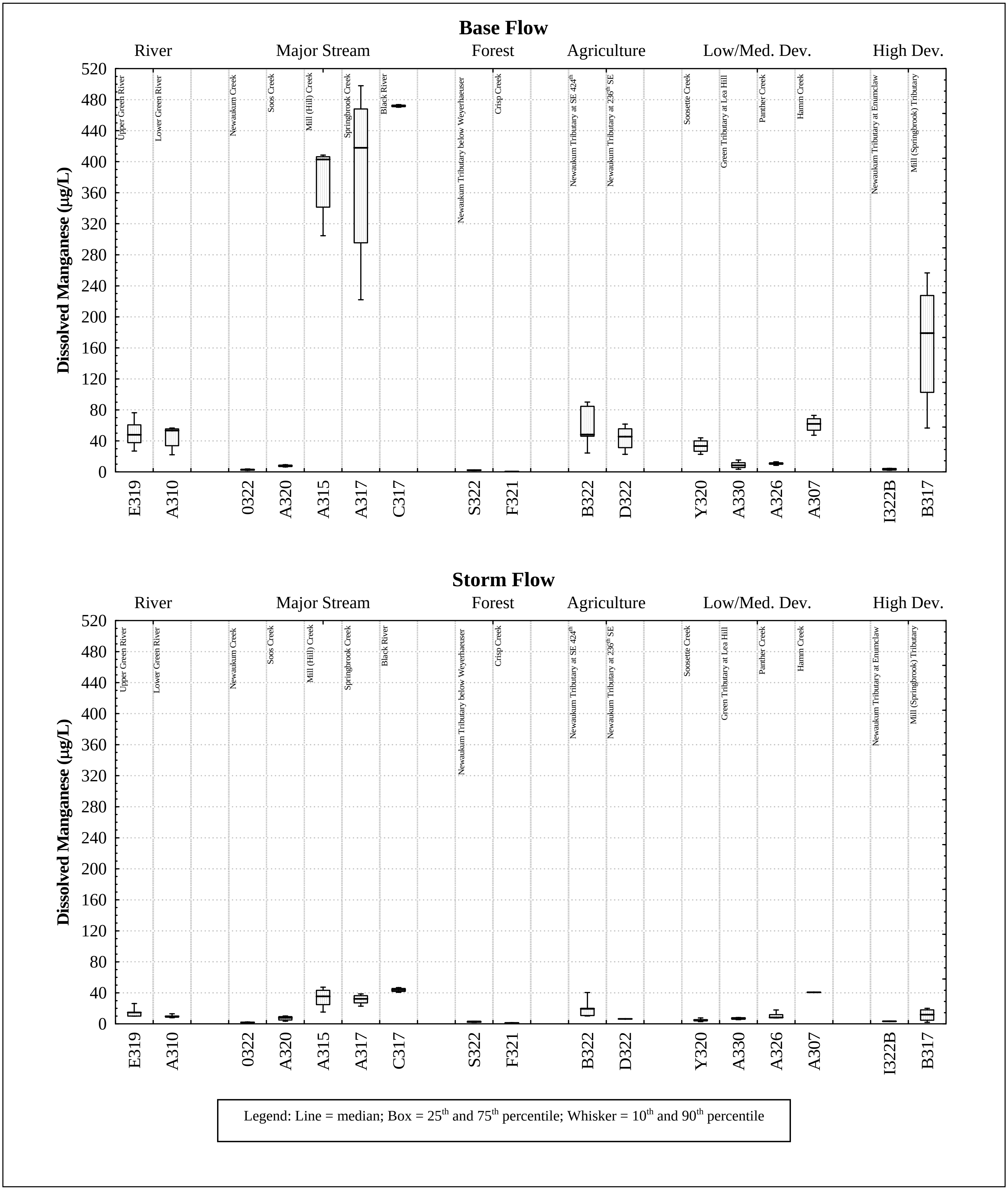


Figure 55. Dissolved manganese concentrations at sites in the Green-Duwamish watershed in 2003.

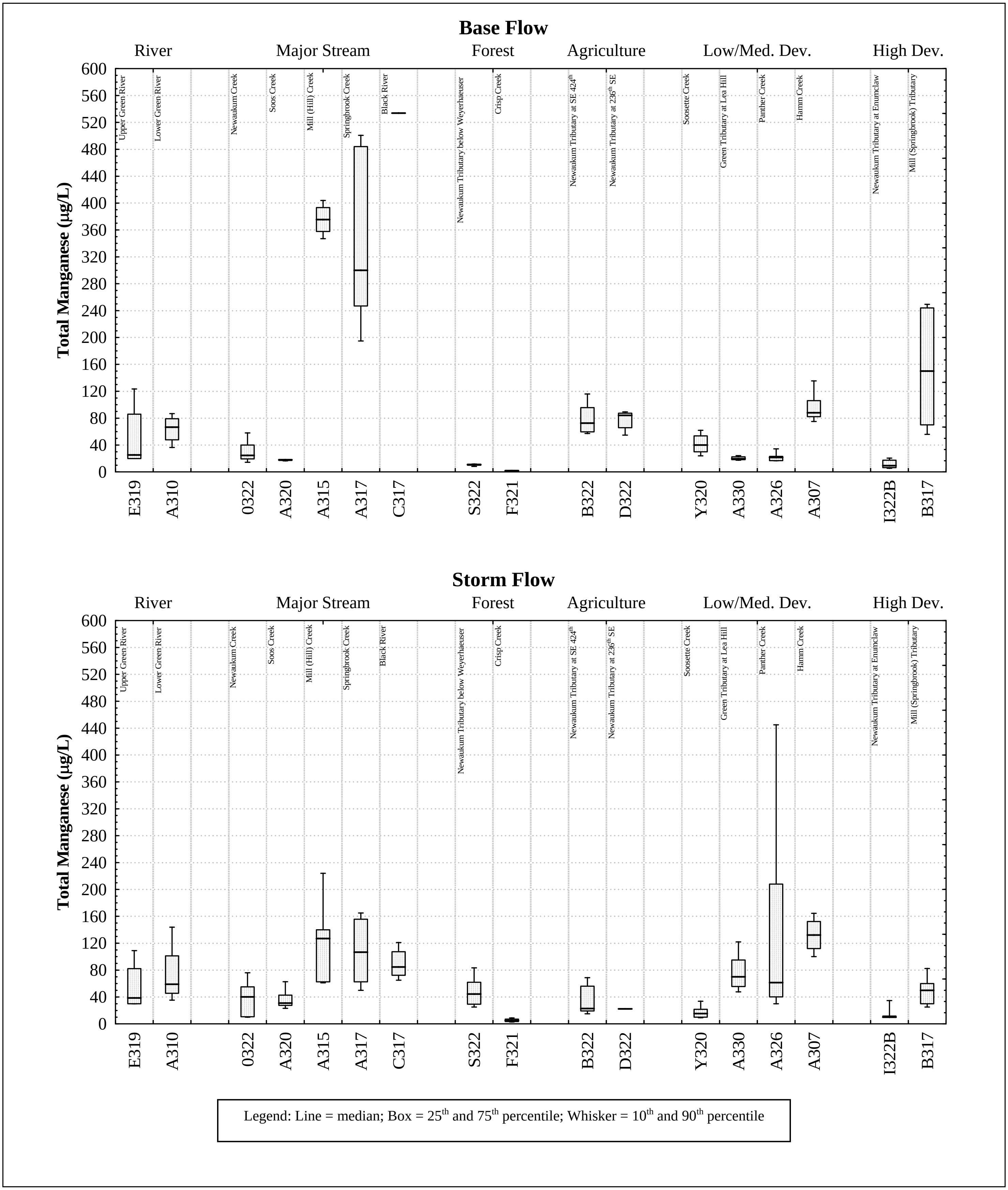


Figure 56. Total manganese concentrations at sites in the Green-Duwamish watershed in 2003.

concentrations were significantly higher ($p = 0.0289$) during storm flow in Mill (Hill) Creek (A315) relative to Soos Creek (A320) (Tables P17 and P18, Appendix P).

The tributary sites exhibited manganese concentrations that were similar to those for the major stream sites. Among the tributary sites, the highest dissolved and total manganese concentrations were observed during base flow in the Mill (Springbrook) tributary, but those concentrations did not exceed the manganese concentrations observed at Black River (C317), Springbrook Creek (A317), and Mill (Hill) Creek (A315).

5.3.6.5 Potassium

Summary statistics for dissolved potassium during base and storm flow are presented in Figure 57 (and Table G9, Appendix G). Summary statistics for total potassium during base and storm flow are presented in Figure 58 (and Table G10, Appendix G). Washington State has not established surface water quality criteria for dissolved or total potassium (WAC 173-201A).

For all monitoring sites, dissolved potassium concentrations ranged from less than 2 to 14 mg/L during base flow, and ranged from less than 1 mg/L to 38 mg/L during storm flow. Total potassium concentrations ranged from less than 2 to 14 mg/L during base flow, and ranged from less than 1 mg/L to 37 mg/L during storm flow. As noted for magnesium, nearly all of the potassium present in each sample is in the dissolved state for all sites and flow conditions.

Results of the spatial pattern analysis for the Green River showed that there were no significant differences in dissolved and total potassium concentrations between the upper and lower sites during base flow or storm flow (Table P16, Appendix P), a finding which was also observed in 2001-2002. Spatial pattern analysis results for the major stream sites show that dissolved and total potassium concentrations were not significantly different during base flow, but were significantly higher ($p < 0.002$) during storm flow in Newaukum Creek (0322) relative to the Black River (C317) and Springbrook Creek (A317) (Tables P17 and P18, Appendix P).

Median dissolved and total potassium concentrations were consistently highest during base and storm flow at the two Newaukum tributaries representing agricultural land use (B322 and D322), a finding which was also observed in 2001-2002 (Herrera 2004).

5.3.6.6 Sodium

Summary statistics for dissolved sodium during base and storm flow are presented in Figure 59 (and Table G11, Appendix G). Summary statistics for total sodium during base and storm flow are presented in Figure 60 (and Table G12, Appendix G). Washington State has not established surface water quality standards for dissolved or total sodium (WAC 173-201A).

Dissolved sodium concentrations ranged from 2.3 to 40.2 mg/L during base flow, and from 1.6 to 20.1 mg/L during storm flow. Total sodium concentrations exhibited similar ranges (i.e., from 2.4 to 41.4 mg/L during base flow and from 1.7 to 20.0 mg/L during storm flow) because nearly all of the sodium present in the samples was in the dissolved state.

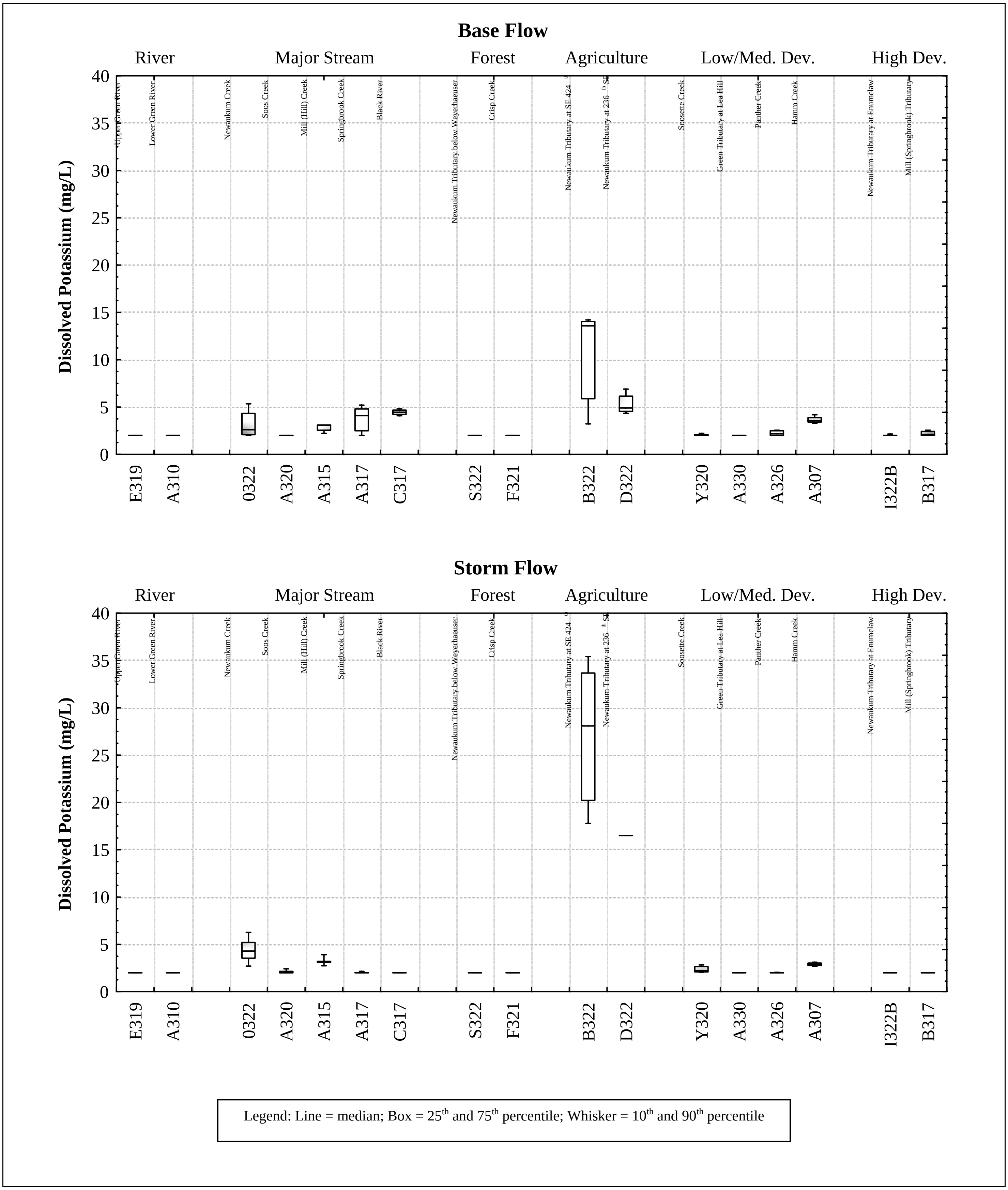


Figure 57. Dissolved potassium concentrations at sites in the Green-Duwamish watershed in 2003.

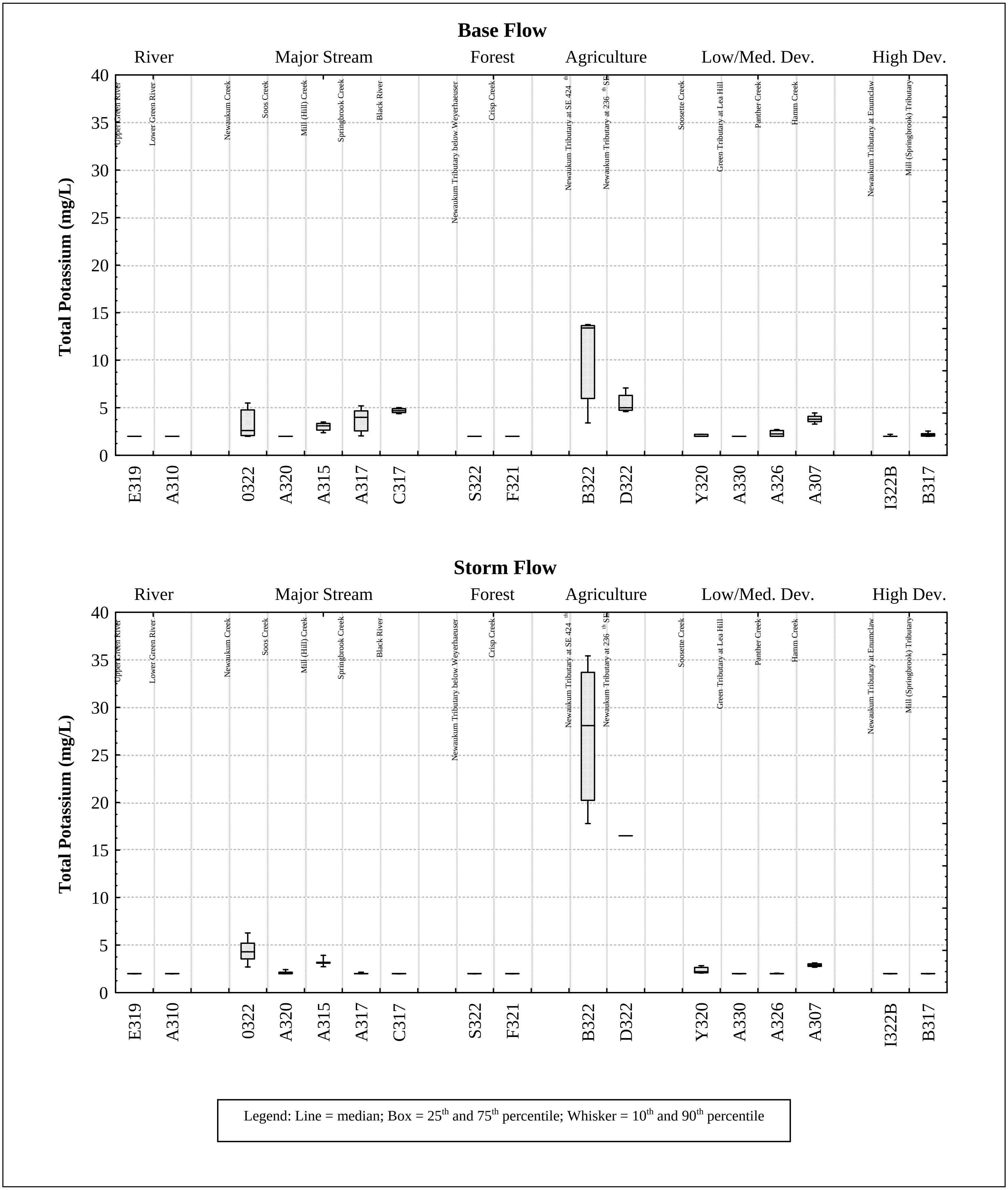


Figure 58. Total potassium concentrations at sites in the Green-Duwamish watershed in 2003.

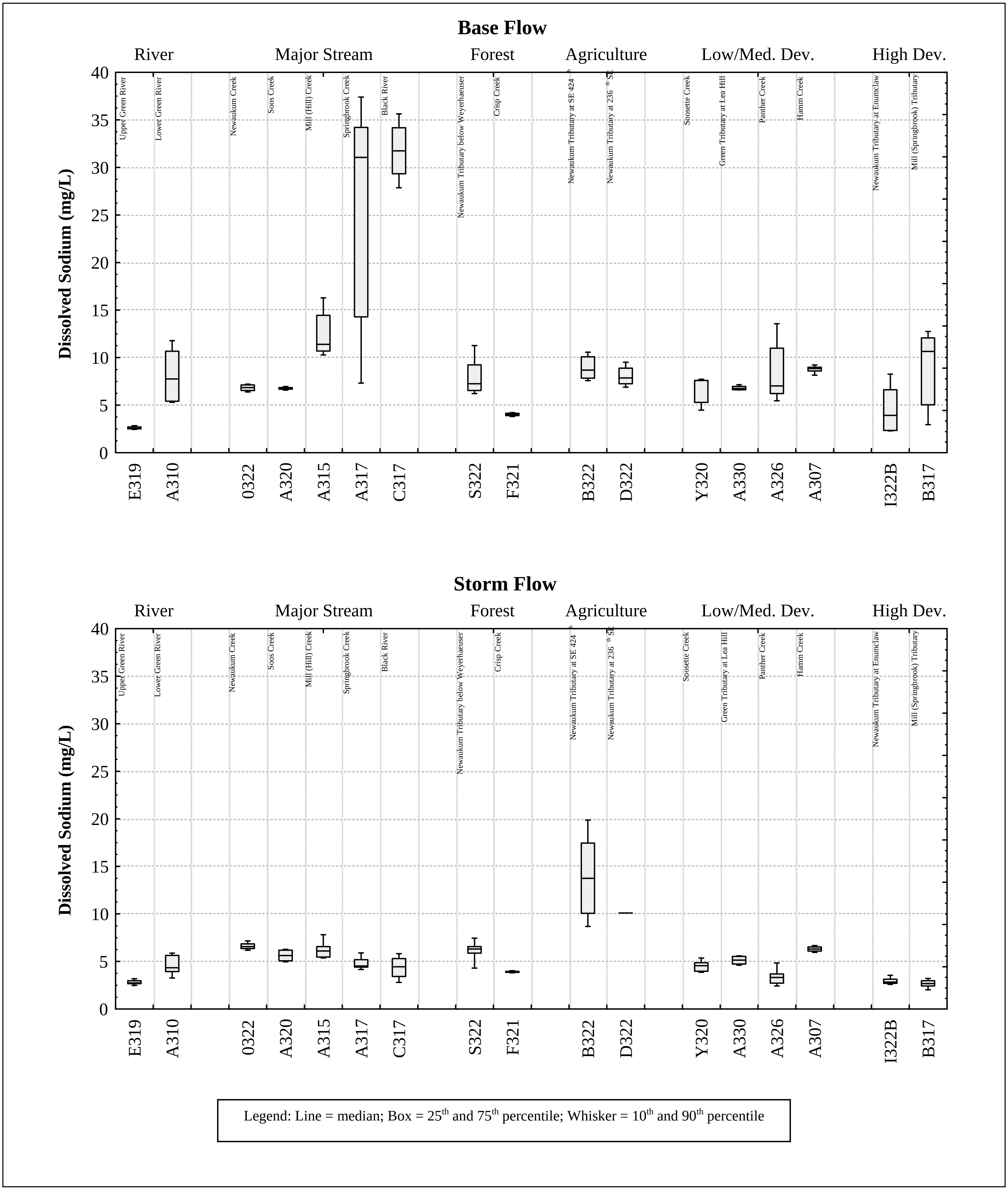


Figure 59. Dissolved sodium concentrations at sites in the Green-Duwamish watershed in 2003.

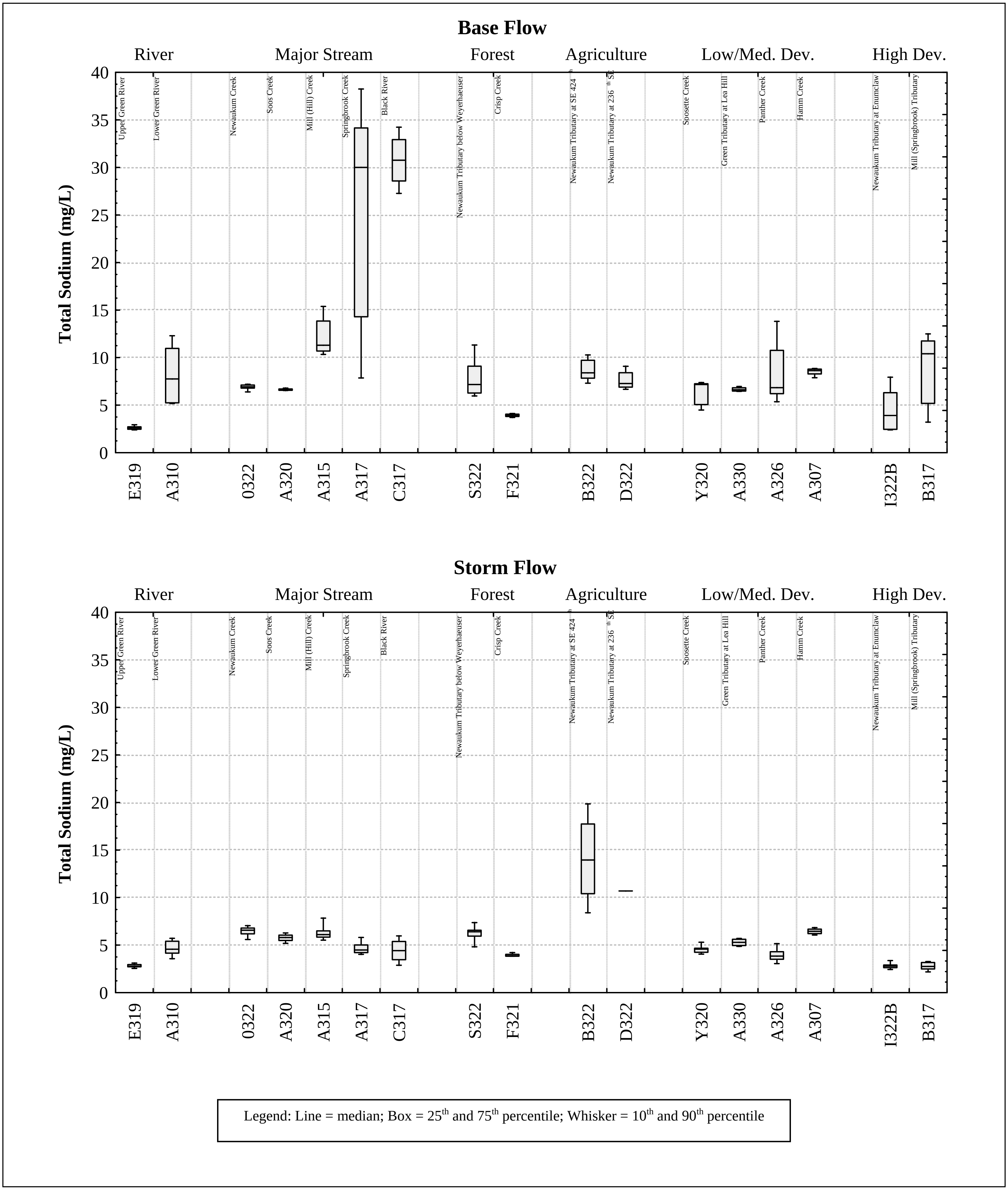


Figure 60. Total sodium concentrations at sites in the Green-Duwamish watershed in 2003.

Spatial pattern analysis results for the Green River sites show that dissolved and total sodium concentrations significantly increased downstream during both base flow and storm flow ($p < 0.020$) (Tables P16 and P17, Appendix P). Median total sodium concentrations increased downstream from 2.6 to 7.8 mg/L during base flow, and increased downstream from 2.8 to 4.6 mg/L during storm flow.

Results of the spatial pattern analysis for the major stream sites show that dissolved sodium concentrations were significantly higher ($p = 0.0313$) during base flow in the Black River (C317) relative to Soos Creek (A320) and were significantly higher ($p = 0.0223$) during storm flow in Newaukum Creek (0322) relative to the Black River (C317) (Tables P17 and P18, Appendix P). Total sodium concentrations were significantly higher ($p = 0.0234$) during base flow in the Black River (C317) relative to Soos Creek (A320), and were significantly higher ($p = 0.0259$) during storm flow in Newaukum Creek (0322) relative to Springbrook Creek (A317). Previously, there were no significant differences in dissolved or total sodium concentrations during storm flow among the major stream sites in 2001-2002 (Herrera 2004).

The tributary sites exhibited sodium concentrations that were similar to those for the major stream sites with the exception that median dissolved sodium concentrations during storm flow were highest at the two Newaukum tributary sites representing agricultural land use (B322 and S322), an observation also made in 2001-2002 (Herrera 2004).

5.3.7 Organics

This section summarizes results for organic compounds based on the data collected in 2003 for the GDWQA. Summary statistics for these parameters are presented in Appendix H through Appendix O, but are not presented graphically due to the infrequency with which organic contaminants were detected. Presentation of these results is organized into separate subsections for the following categories of priority pollutant organic compounds:

- Halogenated hydrocarbons
- Phenols
- Phthalates
- Polycyclic aromatic hydrocarbons (PAHs)
- Polychlorinated biphenyls (PCBs)
- Miscellaneous semivolatile organics
- Chlorinated and organophosphorus pesticides
- Chlorinated herbicides.

5.3.7.1 Halogenated Hydrocarbons

Selected base and storm flow samples from the two Green River sites and five major stream sites were analyzed for the following halogenated hydrocarbons:

- 1,2,4-Trichlorobenzene
- 1,2-Dichlorobenzene
- 1,3-Dichlorobenzene
- 1,4-Dichlorobenzene
- 2-Chloronaphthalene
- 3,3'-Dichlorobenzidine
- 4-Bromophenylphenylether
- 4-Chloroaniline
- 4-Chlorophenylphenylether
- Bis(2-chloroethoxy)methane
- Bis(2-chloroethyl)ether
- Bis(2-chloroispropyl)ether
- Hexachlorobenzene
- Hexachlorobutadiene
- Hexachloroethane.

None of these compounds are regulated by Washington State (WAC 173-201A) or EPA (2002a) for toxicity to aquatic organisms in surface waters.

None of the halogenated compounds were detected in the collected samples (see Tables H1 through H15, Appendix H). Detection limits ranged from 0.01 to 0.05 µg/L (with the exception of 4-chloroaniline where the detection limits were 0.24 to 0.25 µg/L, and 3,3'-dichlorobenzidine where detection limits ranged from 0.71 to 0.75 µg/L).

5.3.7.2 Phenols

Selected base and storm flow samples from the two Green River sites and five major stream sites were analyzed for the following phenols:

- 2,4,5-Trichlorophenol
- 2,4,6-Trichlorophenol
- 2,4-Dichlorophenol
- 2,4-Dimethylphenol
- 2,4,-Dinitrophenol
- 2-Chlorophenol
- 2-Methylphenol
- 2-Nitrophenol
- 4,6-Dinitro-2-methylphenol
- 4-Chloro-3-methylphenol
- 4-Methylphenol
- 4-Nitrophenol
- Pentachlorophenol
- Phenol.

Washington State surface water quality standards (WAC 173-201A) include acute and chronic criteria for pentachlorophenol (see Table 14), which vary with pH but are well above the method detection limit (i.e., any value that would have exceeded the criteria would have been detected).

None of these parameters were detected with the exception of 4-methylphenol and phenol (see Tables I11 and I14, Appendix I). The compound 4-methylphenol was detected in one storm sample at a low concentration (1.20 µg/L) from Mill (Hill) Creek (A315). Phenol concentrations ranged from less than 0.09 to 0.67 µg/L, and phenol was detected in one or two samples collected from all sites except Lower Green River (A310).

5.3.7.3 Phthalates

Selected base and storm flow samples from the two Green River sites and five major stream sites were analyzed for the following phthalates:

- Bis(2-ethylhexyl)phthalate
- Butylbenzylphthalate
- Diethylphthalate
- Dimethylphthalate
- Di-n-butylphthalate
- Di-n-octylphthalate.

None of these compounds are regulated by Washington State (WAC 173-201A) or the EPA (2002a) for toxicity to aquatic organisms in surface waters.

Phthalate concentrations ranged from less than 0.01 to 0.34 µg/L, with the exception of bis(2-ethylhexyl)phthalate which exhibited a maximum concentration of 15.80 µg/L. Phthalates were rarely detected. Bis(2-ethylhexyl)phthalate was only detected in one base flow sample from Newaukum Creek (0322) (Table J1, Appendix J). Butylbenzylphthalate was not detected in any sample (Table J2, Appendix J). Diethylphthalate was only detected in one storm flow sample from Black River (C317) (Table J3, Appendix J). Dimethylphthalate was only detected in one storm flow sample from Mill (Hill) Creek (A315) (Table J4, Appendix J), di-n-butylphthalate was not detected in any sample (Table J5, Appendix J), and di-n-octylphthalate (Table J6, Appendix J) was detected in two samples from Mill (Hill) Creek (A315) during storm flow.

However, as noted in the QA Review memorandum (Appendix A), blank contamination was observed for all phthalate parameters, and it was recommended that the MDLs be raised by a factor of 10. Although the phthalate MDLs were not raised in the database, all phthalate concentrations should be regarded as undetected because they were less than 10 times the MDL, with the exception of one value for deithylphthalate (0.14 µg/L at site C317) and one value for bis(2-ethylhexyl)phthalate (15.8 µg/L at site 0322).

5.3.7.4 Polycyclic Aromatic Hydrocarbons (PAHs)

Selected base and storm flow samples from the two Green River sites and five major stream sites were analyzed for the following polycyclic aromatic hydrocarbons (PAHs):

- 2-Methylnaphthalene
- Acenaphthene
- Acenaphthylene
- Anthracene
- Benzo(a)anthracene
- Benzo(a)pyrene
- Benzo(b)fluoranthene
- Benzo(k)fluoranthene
- Benzo(g,h,i)perylene
- Chrysene
- Dibenzo(a,h)anthracene
- Fluoranthene
- Fluorene
- Indeno(1,2,3-cd)pyrene
- Naphthalene
- Phenanthrene
- Pyrene.

None of these compounds are regulated by Washington State (WAC 173-201A) or the EPA (2002a) for toxicity to aquatic organisms in surface waters.

The range of detected PAH concentrations was from less than 0.01 to 0.11 µg/L (see Tables K1 through K15, Appendix K). The compounds 2-methylnaphthalene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(g,h,i)perylene, dibenzo(a,h)anthracene, fluorene, and indeno(1,2,3-cd)pyrene were not detected in any sample. The compounds benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, phenanthrene, and pyrene were detected frequently (in at least three samples) at Black River (C317), while acenaphthene, chrysene, fluoranthene, and naphthalene were detected infrequently at this site. The compounds benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, fluoranthene, phenanthrene, and pyrene were detected infrequently at Mill (Hill) Creek (A315). Acenaphthene, benzo(b)fluoranthene, chrysene, fluoranthene, naphthalene, phenanthrene, and pyrene were detected infrequently at Springbrook Creek (A317). Naphthalene was also detected infrequently at Lower Green River (A310) and Soos Creek (A320).

5.3.7.5 Polychlorinated biphenyls (PCBs)

Selected base and storm flow samples from the two Green River sites and five major stream sites were analyzed for the following polychlorinated biphenyls (PCBs):

- Aroclor 1016
- Aroclor 1221
- Aroclor 1232
- Aroclor 1242
- Aroclor 1248
- Aroclor 1254
- Aroclor 1260.

Washington State surface water quality standards (WAC 173-201A) include an acute criterion of 2.0 µg/L and a chronic criterion of 0.014 µg/L for total PCBs.

None of the individual PCBs were detected in the collected samples at detection limits ranging from 0.04 to 0.06 µg/L (see Tables L1 through L7, Appendix L). These detection limits are well below the acute criterion, but exceed the chronic criterion for total PCBs.

5.3.7.6 Miscellaneous Semivolatile Organics

Selected base and storm flow samples from the two Green River sites and five major stream sites were analyzed for the following miscellaneous semivolatile organics:

- 2,4-Dinitrotoluene
- 2,6-Dinitrotoluene
- 3,5,5-Trimethyl-2-cyclohexene-1-one
- 2-Nitroaniline
- 3-Nitroaniline
- 4-Nitroaniline
- Caffeine
- Carbazole
- Dibenzofuran
- Nitrobenzene
- N-nitroso-di-methylamine
- N-nitroso-di-n-propylamine
- N-nitrosodiphenylamine
- Phorate.

None of these compounds are regulated by Washington State (WAC 173-201A) or EPA (2002a) for toxicity to aquatic organisms in surface waters.

Caffeine was detected at all sites except Upper Green River (E319) and the Lower Green River (A310) at concentrations ranging from 0.02 to 0.64 µg/L (see Table M7, Appendix M). The highest caffeine concentrations were observed during storm flow in the Black River (C317).

The remaining semivolatile organics were not detected at detection limits ranging from 0.01 to 0.11 µg/L (with the exception of elevated detection limits ranging from 0.47 to 0.50 µg/L for 3-nitroaniline and 4-nitroaniline, and ranging from 0.24 to 0.25 µg/L for n-nitrosodiphenylamine) (see Tables M1 through Table M14, Appendix M).

5.3.7.7 Chlorinated and Organophosphorus Pesticides

Selected base and storm flow samples from the two Green River sites and five major stream sites were analyzed for chlorinated and organophosphorus pesticides. Chlorinated pesticides include:

- 4,4'DDD
- 4,4'DDE
- 4,4'DDT
- Aldrin
- Alpha-BHC
- Beta-BHC
- Delta-BHC
- Gamma-BHC (lindane)
- Chlordane
- Dieldrin
- Endosulfan I
- Endosulfan II
- Endosulfan sulfate
- Endrin
- Endrin aldehyde
- Heptachlor
- Heptachlor epoxide.

Organophosphorus pesticides include:

- Camphechlor (toxaphene)
- Chlorpyriphos
- Diazinon
- Disulfoton
- Malathion
- Methoxychlor
- Methyl parathion
- Parathion.

Washington State surface water quality standards (WAC 173-201A) include acute and chronic criteria for 4,4'DDT, (and the metabolites 4,4'DDD and 4,4'DDE), aldrin (and the metabolite dieldrin), gamma-BHC (lindane or hexachlorocyclohexane), chlordane, chlorpyriphos, endosulfan (I and II), endrin, heptachlor, and parathion (see Table 14). U.S. EPA (2002) water quality criteria include acute and chronic criteria for camphechlor (toxaphene) and heptachlor epoxide, and include chronic criteria for malathion and methoxychlor (see Table 15).

None of the pesticides were detected in the collected samples at a detection limit of 0.005 µg/L for the chlorinated pesticides (see Tables N1 through Table N18, Appendix N) or at detection limits ranging from 0.02 to 0.05 µg/L for the organophosphorus pesticides (see Tables N19 through N26, Appendix N). These detection limits are less than acute criteria, but exceed chronic criteria for 4,4'DDT (and the metabolites 4,4'DDD and 4,4'DDE), aldrin (and the metabolite dieldrin), camphechlor (toxaphene), chlordane, endrin, heptachlor, and parathion.

5.3.7.8 Chlorinated Herbicides

Selected base and storm flow samples from the two Green River sites and five major stream sites were analyzed for the following chlorinated herbicides:

- Atrazine
- 2,2-Dichloropropionic acid
- 2,4-D
- 2,4-DB
- 2,4,5-T
- Dicamba
- Dichlorprop
- Dinoseb
- MCPA
- MCPP
- Silvex.

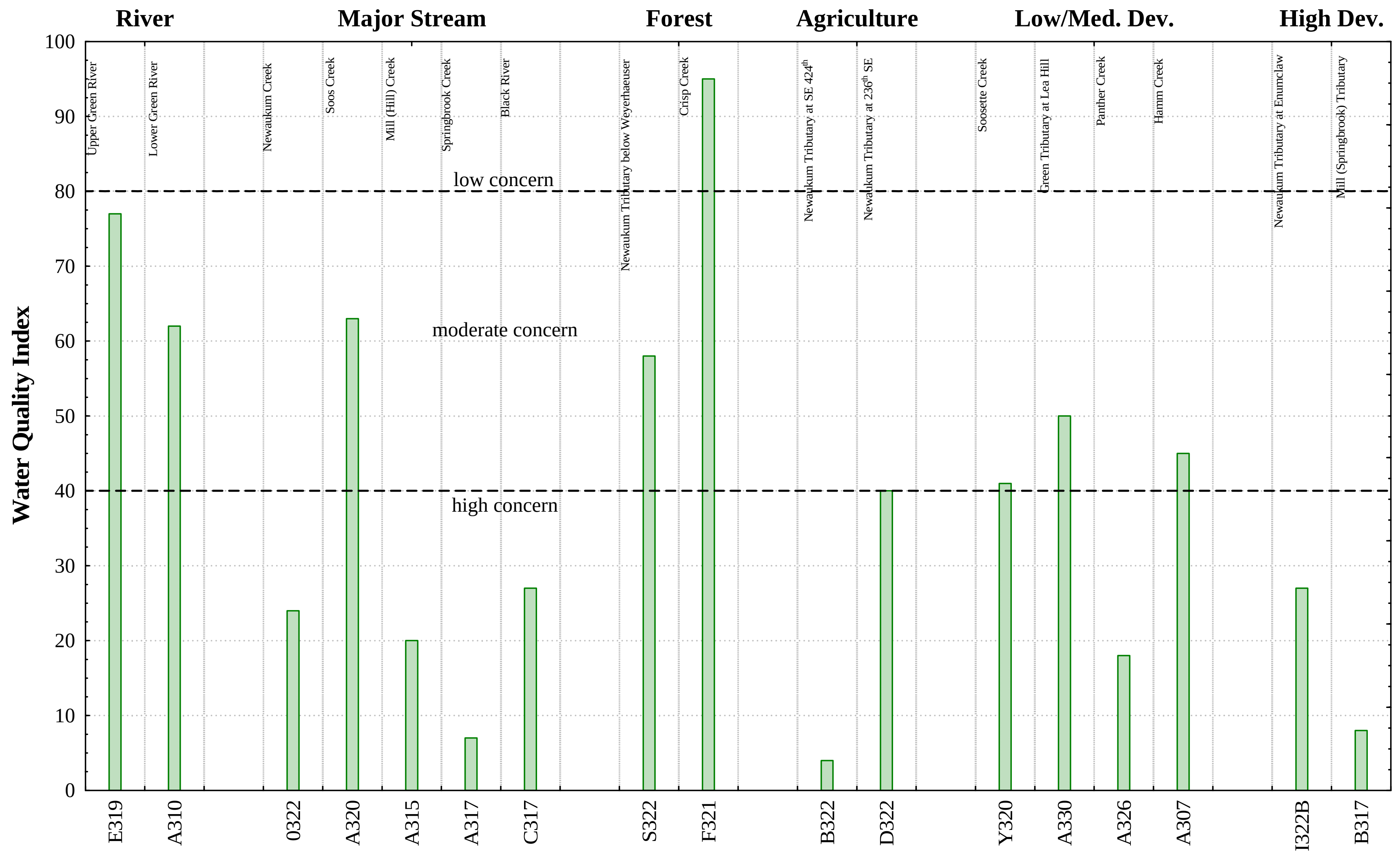
None of these compounds are regulated by Washington State (WAC 173-201A) or U.S. EPA (2002a) for toxicity to aquatic organisms in surface waters.

None of the herbicides were detected at detection limits ranging from 0.01 to 0.08 µg/L, with the following three exceptions (see Tables O1 through Table O11, Appendix O). Atrizine was detected in one storm flow sample (0.98 µg/L) collected from Newaukum Creek (0322) (Table O1, Appendix O). The herbicide 2,4-D was detected in two samples (0.10 µg/L in a base flow sample and 0.37 µg/L in a storm flow sample) collected from Springbrook Creek (A317), and in two samples (0.08 and 0.19 µg/L in storm flow samples) collected from Newaukum Creek (0322) (Table O3, Appendix O). The herbicide dichlorprop was detected in one storm flow sample (0.08 µg/L) collected from Newaukum Creek (0322) (Table O6, Appendix O).

5.3.8 Water Quality Index (WQI) Scores

Calculated water quality index (WQI) scores for each site are summarized in Figure 61. More detailed tabular summaries for the WQI scores are presented in Appendix Q. These tabular summaries include WQI scores for individual samples and parameters from each site. Sites scoring 80 and above likely meet expectations for water quality and are of "low concern", scores between 40 and 79 indicate "moderate concern", and water quality at sites with scores below 40 are likely not meeting expectations and are of "high concern" (Ecology 2002a, 2002b). Based on these criteria, the following sites were identified as being a high concern due to impairment from the indicated parameters (see Section 4.5 for results of the eight parameters included in the WQI score):

- **Newaukum Creek (0322):** high total nitrogen, high total phosphorus
- **Mill (Hill) Creek (A315):** high total nitrogen, high total phosphorus
- **Springbrook Creek (A317):** high total nitrogen, low dissolved oxygen, high total phosphorus
- **Black River (C317):** high total nitrogen, low dissolved oxygen



Scores less than 40 indicate that water quality may not meet designated uses (i.e., high concern) as defined in WAC 173-201A. Scores of 40 to 79 indicate moderate concern, and scores of 80 and greater indicate water quality likely meets designated uses (i.e., low concern (Ecology 2002).

Figure 61. Water quality index (WQI) scores for sampling locations in the Green-Duwamish watershed in 2003.

wp4 /wqi figure 61.doc

- **Newaukum tributary at SE 424th (B322):** high fecal coliform bacteria, high total nitrogen, low dissolved oxygen, high total phosphorus

- **Panther Creek (A326):** high total nitrogen

- **Newaukum tributary at Enumclaw (I322B):** high total nitrogen

- **Mill (Springbrook) tributary (B317):** high total nitrogen.

Specific sources of water quality impairment at these sites (e.g., high fecal coliform bacteria, low dissolved oxygen, and high nutrients) are related to specific activities that occur in association with various types of land use. For example, common sources of fecal coliform bacteria contamination from urban and residential land use include failing septic systems, municipal wastewater discharges, leaking wastewater conveyance systems or side sewers, cross-connections with municipal wastewater systems, and pet and other animal wastes. Low dissolved oxygen concentrations in urban and residential settings can be related to flow reductions, riparian canopy alterations that reduce shading and increase water temperatures (colder water retains more oxygen), inputs of organic matter from animal wastes or municipal wastewater discharges (oxygen is depleted during the decomposition of organic matter), and nutrient inputs from stormwater runoff that contribute to increased algae growth and eutrophication. Fertilizer applications are common sources of nitrogen and phosphorus contamination in stormwater runoff arising from residential areas.

The drainage basin associated with Newaukum tributary at SE 424th (B322) contains a significant amount of land area that is utilized for agricultural purposes. Therefore, impairment at this site from fecal coliform bacteria is likely related to livestock waste. Similarly, high nutrient concentrations at this site are also likely related to the erosion of nutrient-rich soils from cultivated fields. The decomposition of organic matter in water and sediment also depletes dissolved oxygen levels.

The following sites were identified as being of moderate concern due primarily to impairment from high total nitrogen:

- Upper Green River (E319)
- Lower Green River (A310)
- Soos Creek (A320)
- Newaukum tributary below Weyerhaeuser (S322)
- Newaukum tributary 236th SE (D322)
- Soosette Creek (Y320)
- Green tributary at Lea Hill (A330)
- Hamm Creek (A307).

Crisp Creek (F321) is the only site identified as being a low concern for water quality impairment. The high WQI score (95) for this site is related to the relatively undisturbed, forested condition in its associated drainage basin that resulted in high scores for all parameters except total nitrogen.

6.0 Conclusions

Results from water quality monitoring conducted during 2003 for the Green-Duwamish Watershed Water Quality Assessment are summarized below for select monitoring parameters, followed by a summary for the monitoring sites.

6.1 Monitoring Parameters

This section summarizes results for select monitoring parameters based on exceedances of the applicable water quality criteria and general patterns relating to storm and base flow concentrations.

6.1.1 In-stream Field Measurements

6.1.1.1 Temperature

During sampling, water temperatures at all river, stream, and tributary sites were generally cool and met applicable state water quality criteria with the exception of one sample from the Upper Green River (E319), Lower Green River (A310), and Black River (C317) during one summer storm event. However, the Comprehensive GDWQA Sampling Program measured temperature on an infrequent basis during the summer. Therefore, these data likely do not reflect maximum summer daily conditions. The reader is directed to consult the *Green-Duwamish Watershed Water Temperature Report* (Taylor Associates and King County 2004) for a more thorough temperature analysis.

6.1.1.2 Dissolved Oxygen

Low dissolved oxygen concentrations not meeting applicable state criteria were observed at Upper Green River (E319), Lower Green River (A310), Springbrook Creek (A317), Black River (C317), Mill Creek (A315), Newaukum Creek (0322), Newaukum tributary at SE 424th (B322), Newaukum tributary at 236th SE (D322), Soosette Creek (Y320), and Newaukum tributary at Enumclaw (I322B). The minimum dissolved oxygen concentrations for all monitoring sites were 3.2 mg/L during base flow (C317) and 3.8 mg/L during storm flow (B322).

6.1.2 Conventionals

6.1.2.1 Turbidity

The median turbidity of all the sites combined was higher during storm flow (9.9 NTU) than base flow (3.1 NTU). Panther Creek (A326) exhibited the highest maximum turbidity value (380 NTU) of all the sites during storm flow. Other sites exhibiting elevated turbidity during storm flow include the Newaukum tributary below Weyerhaeuser (S322) and Green tributary at Lea Hill (A330).

6.1.2.2 Total Suspended Solids

The median total suspended solids concentration for all river, stream, and tributary sites was higher during storm flow (12.4 mg/L) than base flow (4.8 mg/L). Panther Creek (A326) exhibited the highest maximum total suspended solids concentration (698 mg/L) of all sites during storm flow. Median total suspended solids concentrations exceeded 25 mg/L during storm flow at Newaukum tributary below Weyerhaeuser (S322), Green tributary at Lea Hill (A330), and Panther Creek (A326).

6.1.3 Microbiological Testing

6.1.3.1 Fecal Coliform Bacteria

The geometric mean fecal coliform bacteria concentration for all river, stream, and tributary sites was higher during storm flow (300 CFU/100 mL) than during base flow (54 CFU/100 mL). During base flow, the state criteria were exceeded at all sites except the Upper Green River (E319), Soos Creek (320), and Crisp Creek (F321). During storm flow, the state criteria were exceeded at all sites except the Upper Green River (E319) and Crisp Creek (F321). Geometric mean fecal coliform bacteria concentrations exceeded 1,000 CFU/100 mL during storm flow at Mill (Hill) Creek (A315), Springbrook Creek (A317), and the Newaukum tributaries representing agricultural land uses (B322 and D322).

6.1.4 Nutrients

6.1.4.1 Ammonia Nitrogen

Ammonia nitrogen concentrations at all sites were less than 1.0 mg/L during base and storm flow and met applicable water quality criteria.

6.1.4.2 Nitrate+nitrite and Total Nitrogen

Median nitrate+nitrite nitrogen concentrations exceeded 1.0 mg/L during base and storm flow at Newaukum Creek (0322), the two Newaukum tributaries representing agricultural land use (B322 and D322), Hamm Creek (A307), and Newaukum tributary at Enumclaw (I322B). These sites also exhibited the highest total nitrogen concentrations.

6.1.4.3 Phosphorus

Median orthophosphate phosphorus concentrations exceeded 0.030 mg/L during base and storm flow at Newaukum Creek, Mill (Hill) Creek (A315), and the two Newaukum tributaries representing agricultural land use (B322 and D322). High total phosphorus concentrations were also observed at these sites, as well as at Springbrook Creek (A317), and Black River (C317). The Newaukum tributary at SE 424th (B322) exhibited very high orthophosphate and total phosphorus concentrations (maximum of 2.5 mg/L) that greatly exceeded the maximum total phosphorus concentration (0.25 mg/L) for all other sites.

6.1.5 Metals

6.1.5.1 Aluminum

The median total aluminum concentration for all monitoring sites was higher during storm flow (590 µg/L) than during base flow (95 µg/L). During base flow sampling, the U.S. EPA chronic criterion for total aluminum (87 µg/L) was exceeded at all sites except Soos Creek (A320), Black River (C317), and Crisp Creek (F321). During storm flow sampling, the acute criterion for total aluminum (750 µg/L) was exceeded at all sites except Newaukum tributary at 236th SE (D322).

6.1.5.2 Cadmium and Lead

Lead and cadmium concentrations were generally low at all sampling sites and did not exceed applicable state criteria for the dissolved fraction during base or storm flow sampling.

6.1.5.3 Copper and Zinc

Median concentrations of copper and zinc for all monitoring sites were higher during storm flow than during base flow. Copper and zinc concentrations were generally low during base and storm flow sampling, and did not exceed state criteria in the Green River and major streams. However, the acute criterion for dissolved zinc was exceeded on one occasion during storm flow at Mill (Springbrook) tributary (29.6 µg/L dissolved zinc at site B317).

6.1.5.4 Mercury

Median dissolved and total mercury concentrations for all sites during base flow and storm flow were at or near the detection limit of 0.0005 µg/L. The acute criterion for dissolved mercury (2.1 µg/L) was not exceeded in any of the samples, but the chronic criterion for total mercury (0.012 µg/L) was exceeded in one base flow sample from Hamm Creek (A307) and one base flow sample from the Mill (Springbrook) tributary (B317).

6.1.6 Priority Pollutant Organics

6.1.6.1 Halogenated Hydrocarbons

Halogenated hydrocarbons were not detected at any site during base or storm flow sampling. (Samples from tributary sites were not analyzed for priority pollutant organics.)

6.1.6.2 Phenols

The compound 4-methylphenol was detected in one storm sample at a low concentration (1.20 µg/L) from Mill (Hill) Creek (A315). Phenol concentrations ranged from less than 0.09 to 0.67 µg/L, and phenol was detected in one or two samples collected from all sites except Lower Green River (A310).

6.1.6.3 Phthalates

Low concentrations of bis(2-ethylhexyl)phthalate, diethylphthalate, dimethylphthalate, and di-n-octylphthalate were detected in one or two samples. However, all but two phthalate values should be considered undetected due to blank contamination.

6.1.6.4 Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) were detected at low concentrations (less than 0.1 µg/L) in the Lower Green River (A310), Soos Creek (A320), Mill (Hill) Creek (A315), and the Black River (C317), but were not detected at the other river and major stream sites.

6.1.6.5 Polychlorinated Biphenyls

Polychlorinated biphenyls (PCBs) were not detected at any river or major stream site during base or storm flow sampling.

6.1.6.6 Miscellaneous Semivolatile Organics

Caffeine was detected at all sites except the Upper Green River (E319) and the Lower Green River (A310) at concentrations ranging from 0.02 to 0.64 µg/L. The highest caffeine concentrations were observed at the Black River (C317). The remaining semivolatile organic compounds were not detected at any site.

6.1.6.7 Pesticides and Herbicides

Chlorinated and orthophosphorus pesticides were not detected in any site during base or storm flow sampling. The herbicide atrazine was detected in one sample from Newaukum Creek (0322). The herbicide 2,4-D was detected in two samples from Springbrook Creek (A317) and two samples from Newaukum Creek (0322). The herbicide dichlorprop was detected in one sample from Newaukum Creek (0322).

6.2 Monitoring Sites

This section summarizes water quality observations for the two sites on the Green River, the five major stream sites, and the 10 tributary sites using comparisons to applicable state or federal water quality criteria and the water quality index scores presented in Figure 61.

6.2.1 Green River

Concentrations of most parameters increased significantly moving downstream in the Green River from site E319 below Howard Hanson Dam to site A310 at Fort Dent Park. State or federal water quality criteria for the following four parameters were exceeded at the upstream site (E319): temperature, dissolved oxygen, total nitrogen, total aluminum. At the downstream site (A310), state or federal criteria were exceeded for the following 10 parameters: temperature, dissolved oxygen, fecal coliform bacteria, enterococci bacteria, *E. coli* bacteria, nitrate+nitrite nitrogen, total phosphorus, total nitrogen, total aluminum, and dissolved cadmium.

The water quality index decreased from upstream to downstream, from 77 to 62 which indicates that beneficial uses are of moderate concern for impairment at both the upstream and downstream site on the Green River. In 2001-2002, the water quality index decreased from upstream to downstream, from 91 to 75 which indicates a similar pattern but high variability between years.

6.2.2 Major Streams

Data analyses conducted for the five major stream sites indicated that concentrations of most parameters were higher at Black River (C317), Springbrook Creek (A317), and Mill (Hill) Creek (A315) than at Soos Creek (A320) and Newaukum Creek (0322). However, Newaukum Creek (0322) exhibited high concentrations of bacteria and nutrients. State or federal water quality criteria were exceeded at one or more of these streams sites for the following parameters: temperature, dissolved oxygen, fecal coliform bacteria, enterococci bacteria, *E. coli* bacteria, nitrate+nitrite nitrogen, total nitrogen, total phosphorus, and total aluminum.

The water quality index score for Soos Creek (A320) was 63, which is within the range of 40 to 79 indicating a moderate concern for impairment of beneficial uses. Water quality index scores for the other four stream sites ranged from 7 to 27, which indicates that the associated beneficial uses may not be supported. Water quality impairment in these streams is most likely related to residential and urban development within the respective stream drainage basins, and to agricultural land use in the Newaukum Creek basin. Compared to 2001-2002 data, water quality index scores decreased for Newaukum Creek but increased for the other major streams in 2003. The decreased water quality index score for Newaukum Creek suggests that agricultural land uses caused more water quality impairment in 2003 than in 2001-2002.

6.2.3 Tributaries

Water quality varied widely among the 10 tributary sites, and was somewhat related to land use activities in the associated drainage basins.

Four tributary sites (Panther Creek [A326], Mill [Springbrook] [B317], Newaukum tributary at SE 424th [B322], and Newaukum tributary at Enumclaw [I322B]) exhibited water quality index scores of less than 40, which indicates that beneficial uses may not be supported. These sites also exhibited scores of less than 40 in 2001-2002. Two of the sites (B317 and I322B) drain high density development, one site (A326) drains low to medium density development, and one site (B322) drains agricultural land use. Based on water quality index scores, the predominant sources of water quality impairment at these four tributary sites were: high fecal coliform bacteria, high total nitrogen and total phosphorus, and low dissolved oxygen concentrations.

Water quality index scores for tributary sites Hamm Creek (A307), Soosette Creek (Y320), Green River tributary at Lea Hill (A330), Newaukum tributary at 236th SE (D322), and Newaukum tributary downstream of Weyerhaeuser (S322) were within the range of 40 to 79, which indicates there is a moderate concern with regard to beneficial uses being supported in these streams. The predominant cause of water quality impairment at these five sites was high total nitrogen. Nutrients are common in runoff from the following land use categories associated with these sites: low to medium density development (sites A307, Y320, and A330), agriculture (site D322), and commercial forestry (site S322).

Only one tributary site (Crisp Creek [F321]) exhibited a water quality index score that exceeded 79, which indicates that beneficial uses are likely supported by land use activities in this subbasin. The high WQI score (95) for this stream appears to be related to the relatively undisturbed, forested condition of its watershed, and the dominating influence of spring water in Crisp Creek.

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